WindSat Preliminary Design Review (PDR)

June 10-11, 1998
Naval Research Laboratory

Agenda - Day 1

Building 222 Auditorium

• Introduction/Overview	Hoskins	0830
• Orbit Selection	Kelm	0900
• System Performance Requirements	Gaiser	0915
• Systems Engineering	Gutwein	0945
• Break		1030
• Payload Environment	Spencer	1045
• Mission Assurance	Mann	1105
• Payload Electronics Overview	Webster	1120
– Antenna Subsystem	Lippincott/Bartlett Pogue Cottle McBirney	1130
• Lunch		1200
– Antenna Subsytem (Continued)		1300
– On-Orbit Calibration Loads	Gaiser	1415
– Payload Receiver	Xavier	1445
– Power Conditioning	Connoly	1545
– Data Handling System (DHS)	Nicholson	1615
– Adjourn		1715

Agenda - Day 2
Building 56 Auditorium

• Software	Crossland	0830
• GPS Receiver	Gonyea	0900
• EAGE	Nicholson	0920
• Mechanical Overview	Purdy	0940
• Mechanical Subsystem	Pontius Koss Cheung Mook Pogue	1000
• Lunch		1215
• Mechanical Subsystem (Continued)		1315
• Calibration & Validation	St Germain	1430
• Payload Integration & Test	Purdy	1500
• WindSat to Spacecraft Interface	Mook	1530
• Mission Operations	Barock	1600
• Action Item Review		1630
• Adjourn		1700

PDR Entry and Exit Criteria

WindSat PDR Entry/Exit Criteria (1 of 2)

Entry

- Define and Present
  - System Level
    - Performance Requirements
    - Error Budgets
    - Interface Requirements
    - Software Requirements/Design
    - System Level Test Plans
    - Design Layouts
    - Functional Block Diagrams
    - Performance and Design Analysis
    - System and Integration Schedule
    - Weight and Power Budget
    - Reliability, Quality Assurance and Safety Plans
    - Draft Mission Operations and Status Mission Planning
    - Environmental Requirements
    - Parts Selection/Qualification Process
    - SRR Action Items Closed

WindSat PDR Entry/Exit Criteria (2 of 2)

- Subsystem Level
  - Basic Design
  - Trades/Analysis
  - Engineer Models/Prototypes
  - Test Flow
  - GSE Requirements
  - Long Lead Items
  - Parts Selection/Qualification Process

Exit

- Satisfactorily Proven Basis for Design Definition

SRR Action Items

SRR Action Items Status

Action Item	Initiator	Deficiency	Action	Status
SRR-001	Jones - ATC/MRSC	Composite Structure “Dryout”	Analysis - Negligible Impact	Closed
SRR-002	Mango - IPO	Clarify/Justify Slipring Life Test	One Time, Unacclerated, No Mass Inertia Model	Closed
SRR-003	Mango - IPO	Polar Option Thermal Requirements	Design	Closed
SRR-006	Petzrick -N6	Duty Cycle	100% Duty Cycle Data Available Over Land	Closed
SRR-007	Petzrick -N6	Box Level Testing	Test Program	Closed

Mission Overview

WindSat Mission Overview

Characteristics/Description:

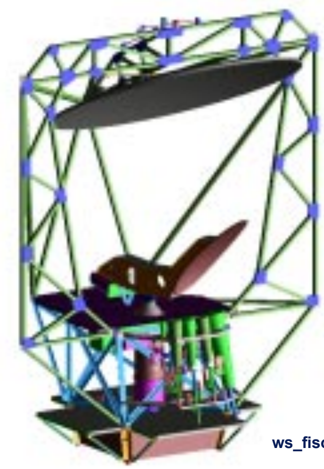
- Measures Ocean Surface Wind Speed, Wind Direction, Using Polarimetric Radiometer on a Modified Satellite Bus, Launched Into a 830 km 98.7° Orbit by the Titan II Launch Vehicle
- 3 Year Design Lifetime

Capability/Improvements:

- Measure Ocean Surface Wind Direction (Non-Precipitating Conditions)
- 3 X Improvement in Horizontal Resolution (Viz. SSMI)
- Secondary Measurements
  - Sea Surface Temperature, Soil Moisture, Rain Rate, Ice, and Snow Characteristics, Water Vapor

Special Features:

- Demonstrate Polarimetric Radiometry
- Risk Reduction for National Polar -Orbiting Operational Environmental Satellite System (NPOESS)
- Space Test Program Satellite Bus
- Sensor to Shooter Direct Data Read-Out
- Highly Leveraged Execution Plan



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What Is the Need?

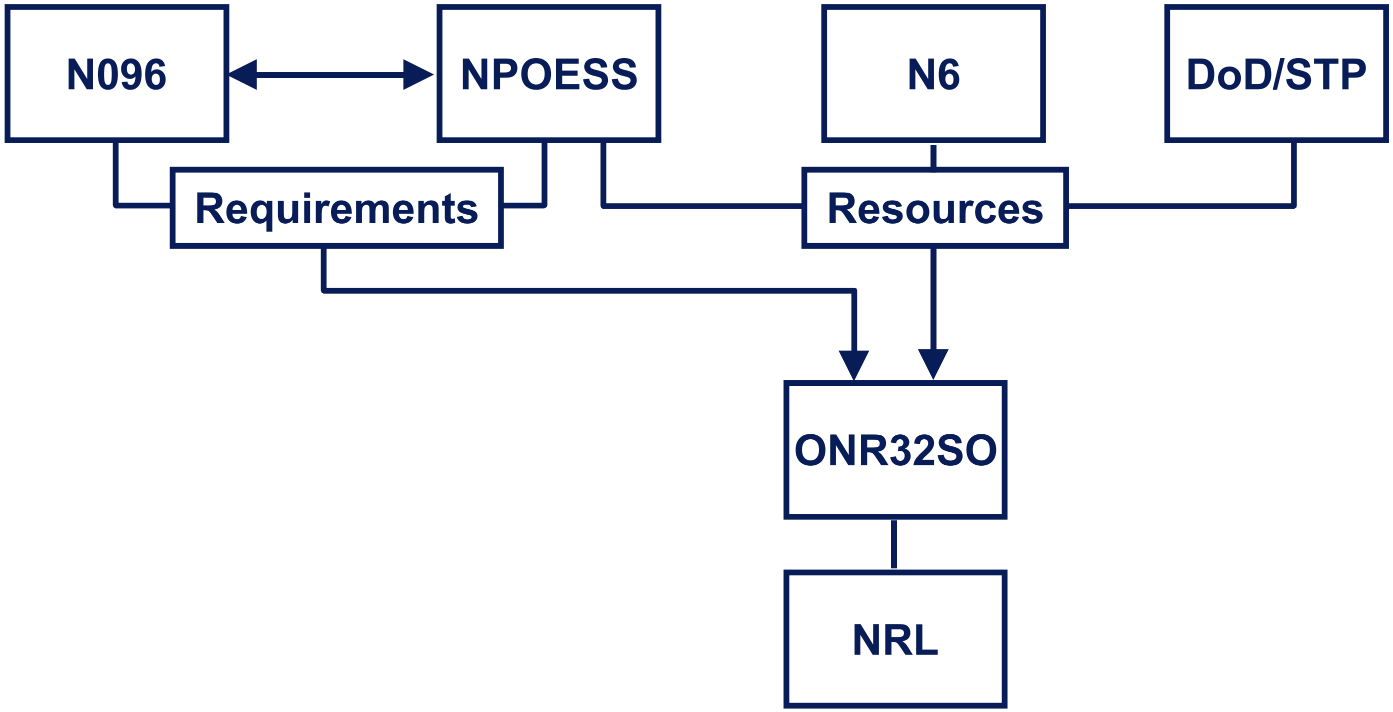
This Program Is Needed Operationally Because:

- **Provides Navy Unique/Mission Critical Sensors and Proof of Concept for Use on NPOESS Satellites**
  - **Current Emphasis Is on Real Time Ocean Surface Wind Speed and Direction**
- **Improves Battlespace Awareness**
  - **Project and Sustain a Forward Presence, Safely**
- **Real-Time On-Scene Tactical Support (Enables Tactical Decision Aids)**
  - **Critical to Precision Guided Munitions, Mission Planning, P(K) Effectiveness**
  - **Protection and Avoidance of Nuclear Biological and Chemical (NBC) Agents**
  - **Optimum Ship Routing and Tropical Cyclone Avoidance**
  - **Surf Index-Amphibious Assault and Special Operations**
  - **Search and Rescue Operations**
- **Program's Relationship to Joint Arena**
  - **Navy Commitment to Joint DoD (DMSP) and Merged DoD/DoC National (NPOESS) Satellite Programs**
  - **Navy Lead in Developing/Maintaining NPOESS Ocean Remote Sensing Technology**

WindSat Mission Objectives

- Demonstrate the Capability of Polarimetric Microwave Radiometry to Measure the Ocean Surface Wind Vector (Speed and Direction) From Space
- Demonstrate Support to the Warfighter With Real Time Tactical Downlink of Radiometer Products Directly From Spacecraft to the Field
- Through Space Test Program, Integrate the Class B/C Developed Sensor and Secondary STP Experiment on a Modified Commercial Spacecraft Bus and Launch Vehicle
- Transfer Technology (Science, Hardware, Algorithm, and Software) to National Converged Weather Satellite Program (NPOESS) for Risk Reduction in Future Systems

WindSat Sponsor, Requirements, and Resource Flow



WindSat Performance Goals

Parameter	Accuracy			Range			Spatial Resolution		
System	WindSat	CMIS	NPOESS/IORD	WindSat	CMIS	NPOESS/IORD	WindSat	CMIS	NPOESS/IORD
Wind Speed	± 2 m/s or 20%			3-25 m/s			25 km*	20 km	
Wind Direction	±20° (3-25m/s)			0-360°			25 km	20 km	

*** Driven by Antenna Size**

WindSat Secondary Products

Parameter	*Accuracy*			*Range*			*Spatial Resolution*		
System	WindSat	CMIS	NPOESS/IORD	WindSat	CMIS	NPOESS/IORD	WindSat	CMIS	NPOESS/IORD
Sea Surface Temperature	0.5C			-2 to 40 C			60 km	50 km	1 km
Soil Moisture (Skin Layer: 0.1 cm Depth)	10 cm/m (Bare Soil with Known Soil Type		±10 cm/m Bare Soil With Known Soil Type (Low Horizontal Resolution-Cloudy) ±20 cm/m (High Resolution-Clear)	0-100 cm/m			60 km	40 km	1 km Clear, Nadir 4 km Clear Worst Case 40 km Cloudy Nadir 50 km Cloudy, Worst Case
Snow Cover	Depth > 0 cm Coverage 20%		± 10% snow/ no snow	Any Depth 0-100%		0 - 40 cm	25 km	12.5 km	1.3 km Clear 12.5 km Cloudy
Sea Ice (Orbit Dependent)	70% Probability of Correct Typing		70% Probability of Correct Typing 1 Yr vs. 2+ Yr ice	First Year, Multi-Year		1 to 36+ month	25 km	20 km	3 km
Water Vapor	2 mm or 10%			0-75 mm			25 km		
Cloud Liquid Water	0.25 mm		±0.50 mm over ocean ±0.25 mm over land	0-50 mm			25 km	20 km	

WindSat Mission Success Criteria (1 of 2)

Within the Program Constraints of a Single Satellite Constellation Consisting of a Government Developed Sensor Integrated Onto a Modified Satellite Bus; Compatible With Titan II Launch Vehicle, Scheduled for Launch February, 2002 Into a 98.7° Inclined Orbit; the Engineering Implementation Shall Provide:

1. **Demonstration of Space-Based Multi-Channel Passive Microwave Polarimetric Radiometry As a Reliable and Cost Effective Means for Measuring Global Ocean Wind Vector (Wind Speed and Direction) Data That Meets Navy and NPOESS Requirements**

2. **Capability to Measure the Following Additional Environmental Data Types, Sea Surface Temperature and Those Generally Associated With Passive Microwave Imagery, Integrated Atmospheric Water Vapor, Cloud Liquid Water, Rain Rate, Sea Ice, Snow Cover, and Soil Moisture**

3. **Direct Downlink Capability to Demonstrate the Capability to Provide On-Scene Users With Near-Real Time Access to the WindSat Data for Retrieval of Wind Vector and the Other Environmental Data Types Outlined in (1) and (2)**

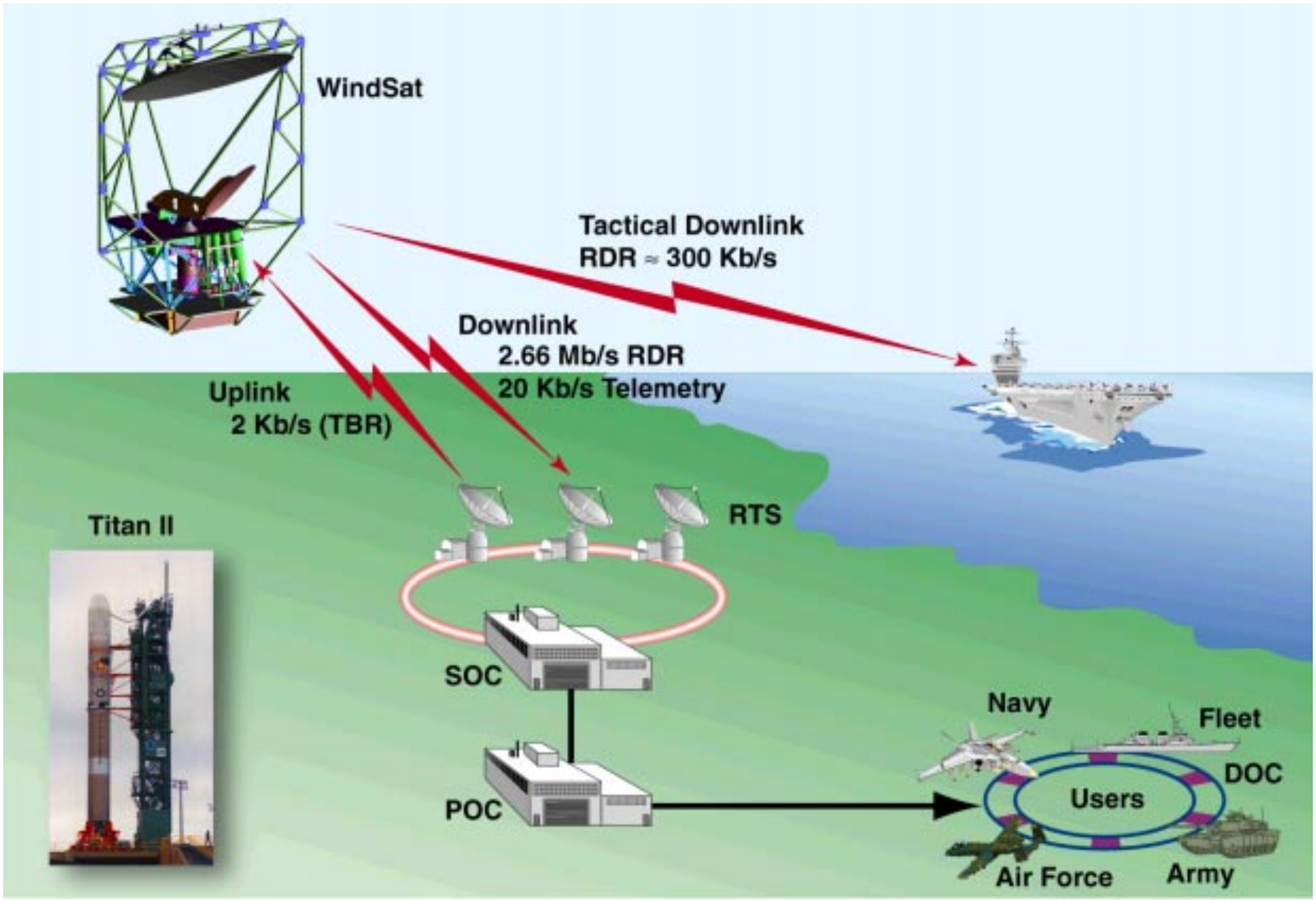
WindSat Mission Success Criteria (2 of 2)

4. Adaptable Into the NPOESS Phase I Ground Control Architecture and Conformance With Command, Control, and Communications (C3) Requirements

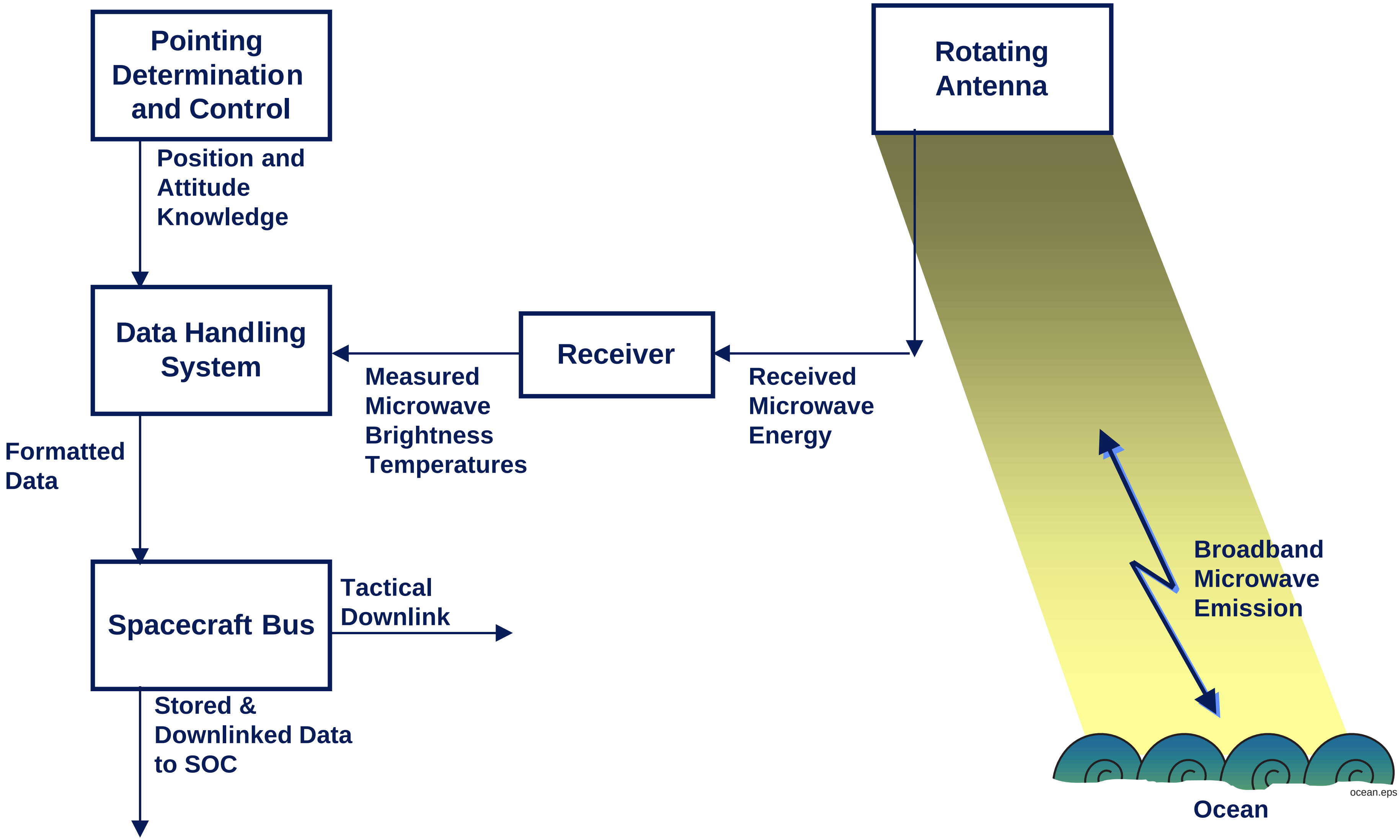
5. Transition of Passive Microwave Polarimetric Radiometry Technology for Use in the Development and Production of the NPOESS Conical Microwave Imagery and Sounder (CMIS)

Element	*WindSat Requirement/Objective*
Mission	
Duration	1 Year/3 Year
Duty Cycle	Ocean/100%
Launch Vehicle	
Orbit	98.7° Inclination 830km Altitude
Secondary STP Experiments	
Duration	One Year
Data Collect	> 6 Months

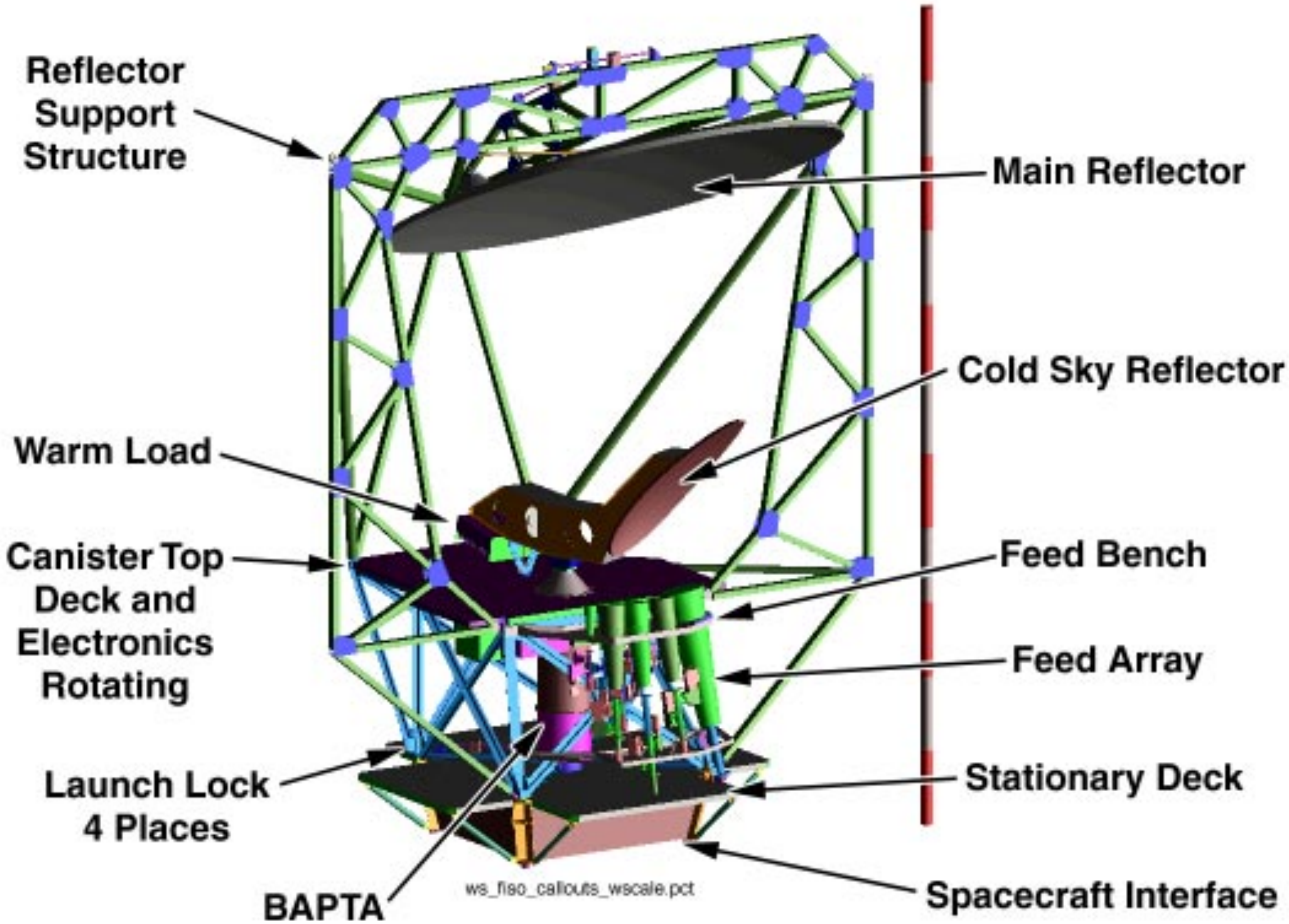
WindSat Top Level Architecture



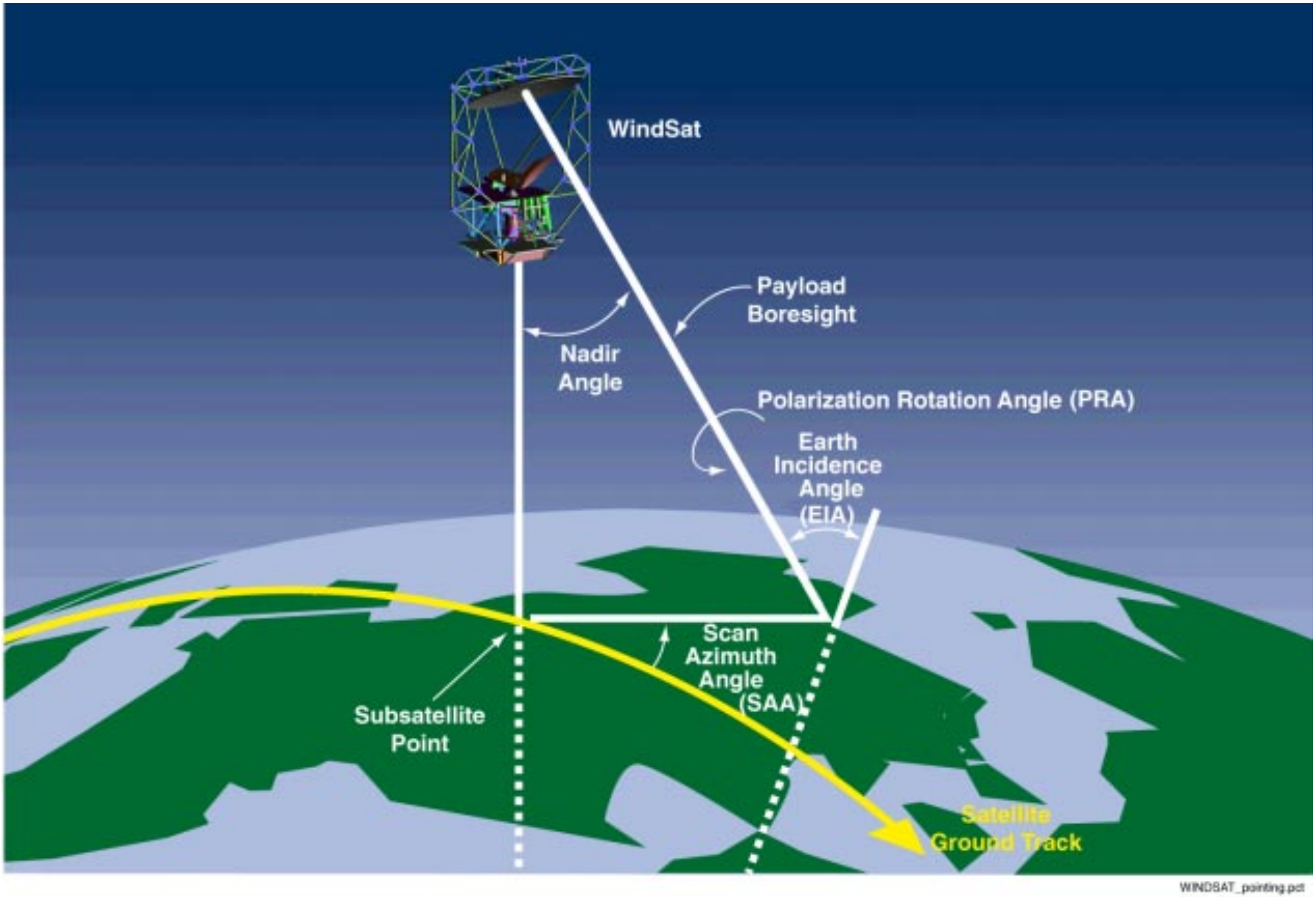
Payload Functionality



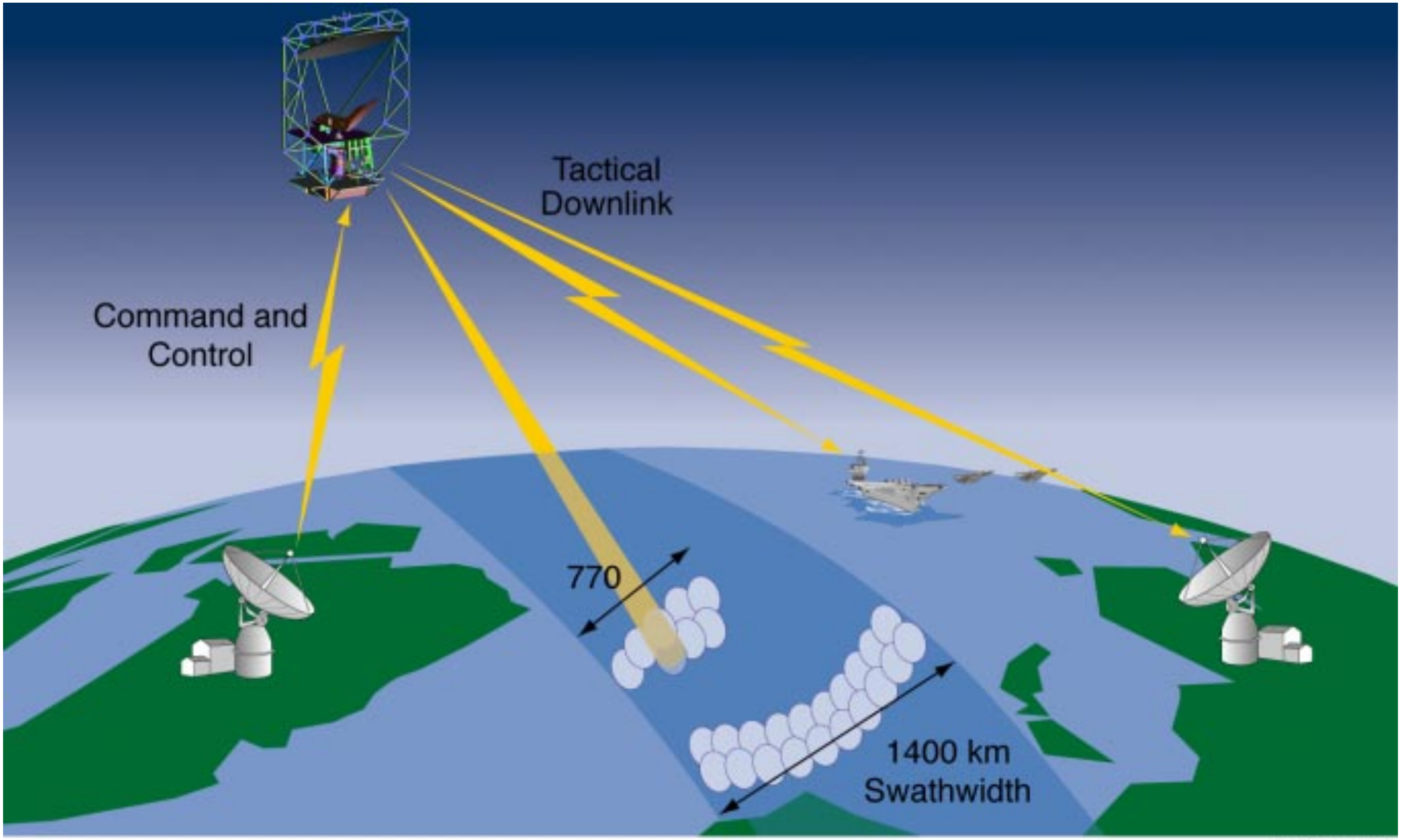
WindSat Concept Definition



WindSat Pointing Definitions



WindSat Swath Width



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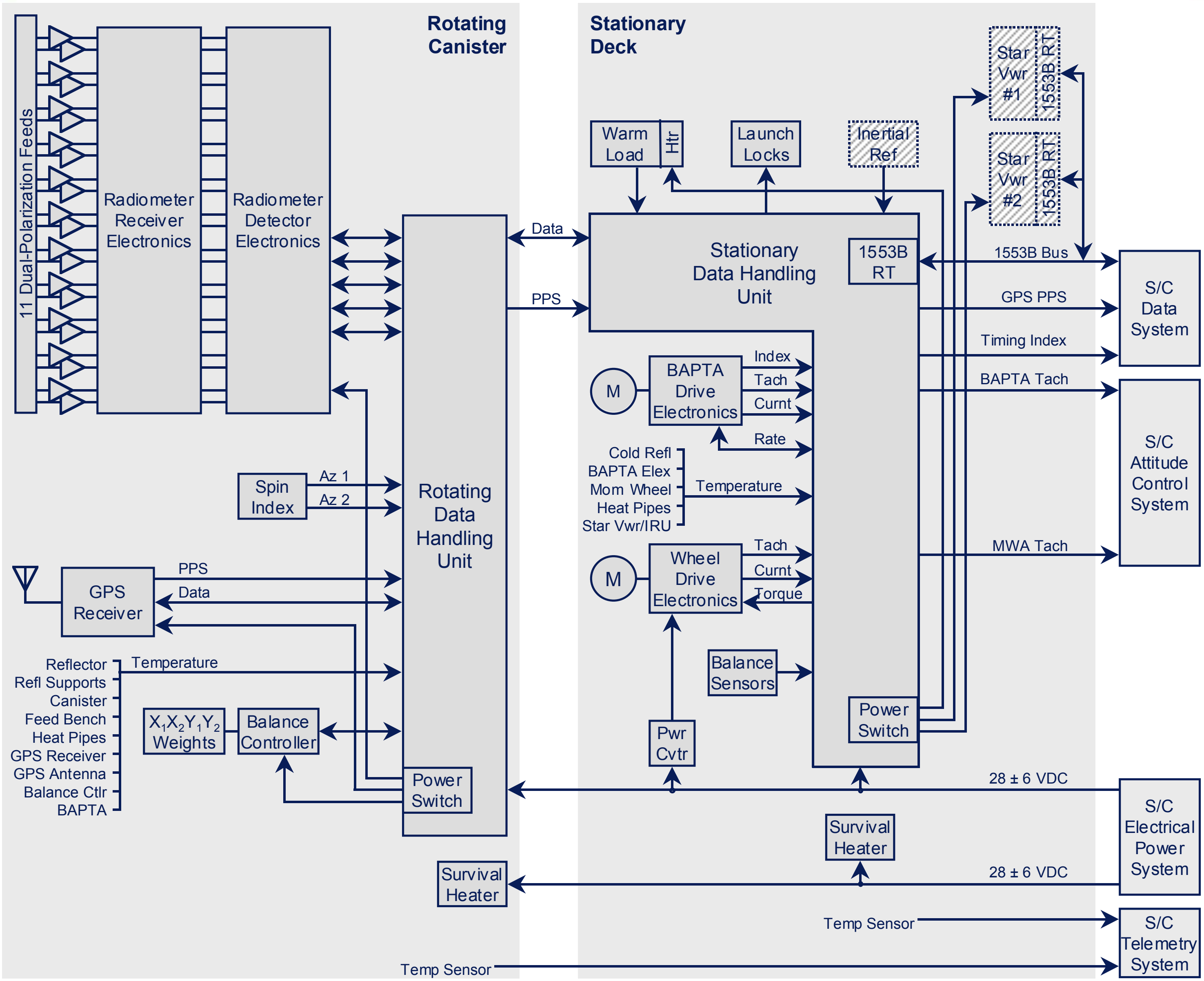
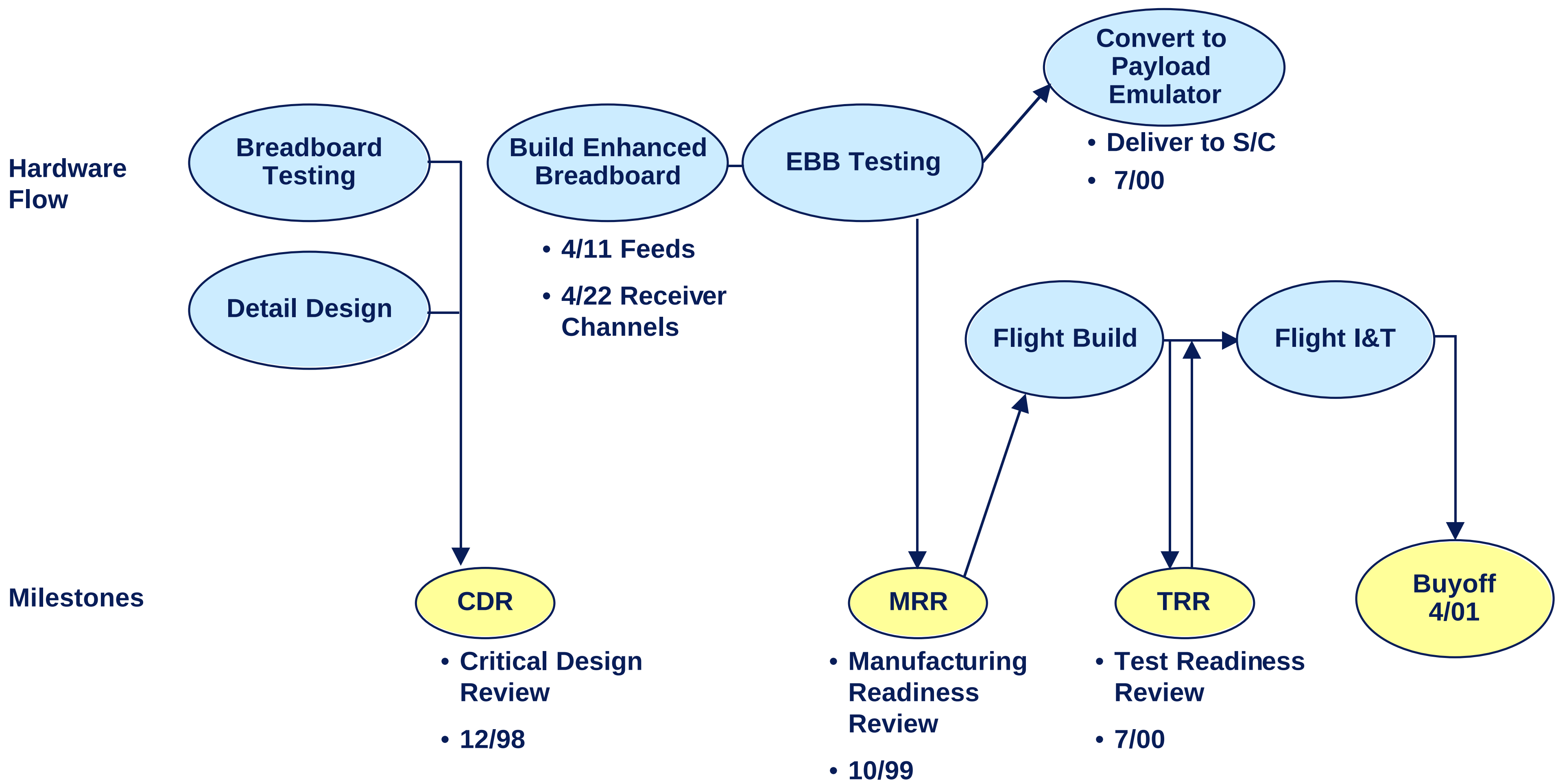
WindSat Electrical Block Diagram



WindSat Development Plan

- CDR Accelerated From February 99 to December 98
  - Detail Design Complete - Limited Test Data
  - Flight Hardware Procurement Delayed to FY00
- Enhanced Breadboard in Place of Engineering Development Models
  - 4 of 11 Feedhorns Active; 4 of 22 Receiver Channels
  - EBB Will Demonstrate Flight Functionality of High Risk Components and Systems Using Non-Flight Equipment Where Feasible
- Manufacturing Readiness Review Established October 99
  - Completion of EBB Testing
  - Prior to Start of Flight Fabrication
- Payload Delivery 4/01
- EBB Updated to Emulator for Spacecraft Testing
  - Delivery 7/00

WindSat Development Plan



Hardware Philosophy

- The WindSat Experiment Is a Demonstration Payload and As Such Will Be Developed As a DOD-HDBK-343 Class B/C Program
  - (B) Medium Life - 3 Years
  - (C) Medium Complexity - Not Developing a Hardware Technology, But May Use State-of-Art
  - (B) Limited Flight Spares - See Sparing Policy
  - (B) Limited Use of Redundancy - Use Only Where Necessary
  - (C) Low Cost - Meet Funding Profile
- Does <u>Not</u> Mean Low Reliability

WindSat Schedule - 3/24/98

Program Milestones	Start Date	Finish Date
Project Start	8/15/97	
Systems Requirements Review	12/16/97	
Detailed Design (Flight/EAGE)	12/17/97	10/1/98
Breadboards	12/17/97	6/1/98
Preliminary Design Review	6/10/98	
Critial Design Review	12/15/98	
Enhanced Breadboard Design	10/1/98	7/1/99
Manufacturing Readiness Review	10/1/99	
Enhanced Breadboard I&T	7/1/99	3/1/00
Flight Unit Build	10/1/99	7/1/00
Flight Unit I&T	7/1/00	4/1/01
Deliver Enhanced Breadboard/Emmulator to S/C	7/1/00	
Test Readiness Review	1/1/01	
P/L Delivery to SC/Buyoff	4/1/01	

Fiscal Year 1998 | Fiscal Year 1999 | Fiscal Year 2000 | Fiscal Year 2001 | Fiscal Year 2002

1997 | 1998 | 1999 | 2000 | 2001 | 2002

Mar 25, 1998

Program Risk and Mitigation

WindSat Risk Watch List

No.	Risk	Type	Level SRR	Level PDR	Mitigation	Who
1	Launch Vehicle	Schedule/ Cost/ Environment	High	Medium	• Monitor Schedule/Development • Envelope Environments/Fairing	Mook
2	Spacecraft	Tech/Cost	High/High	Med/High	• Simplify Interfaces • IDIQ Studies • Experiment Requirement Document	Mook
3	Antenna Pattern Characterization	Tech	High	Low	• Test Range Capabilities/Enhancements • Breadboard Test	Bartlett/ Lippincott
4	Receiver Detector Linearity/System Noise	Tech	High	Low/Med	• Screening Selection Program Testing	Gaiser/Xavier
5	Calibration	Tech	Medium	Medium	• Target Characterization • Availability of APMIR (AF Funds)	Gaiser/ St. Germain
6	EMI/EMC	Schedule Tech	Medium	Medium	• Design/Fab/Test Procedures • EMI Control Plan	Plourde
7	Spin/Slip Ring Assembly	Tech	Medium	Medium	• Redundancy/Contact Design Life Testing Programs	Koss/ Nicholson
8	Polarization Purity	Tech	High	High	• Test and Alignment Procedure Developed • Breadboard Testing	Bartlett/ McBirney

- Risk Watch Items Are Technical and/or Program Issues Identified With Risk That Require Increased Program Visibility
  - Determined During Technical and Project Review - Requires Risk Mitigation Plan - Reviewed and Updated Monthly

Unique WindSat Terms

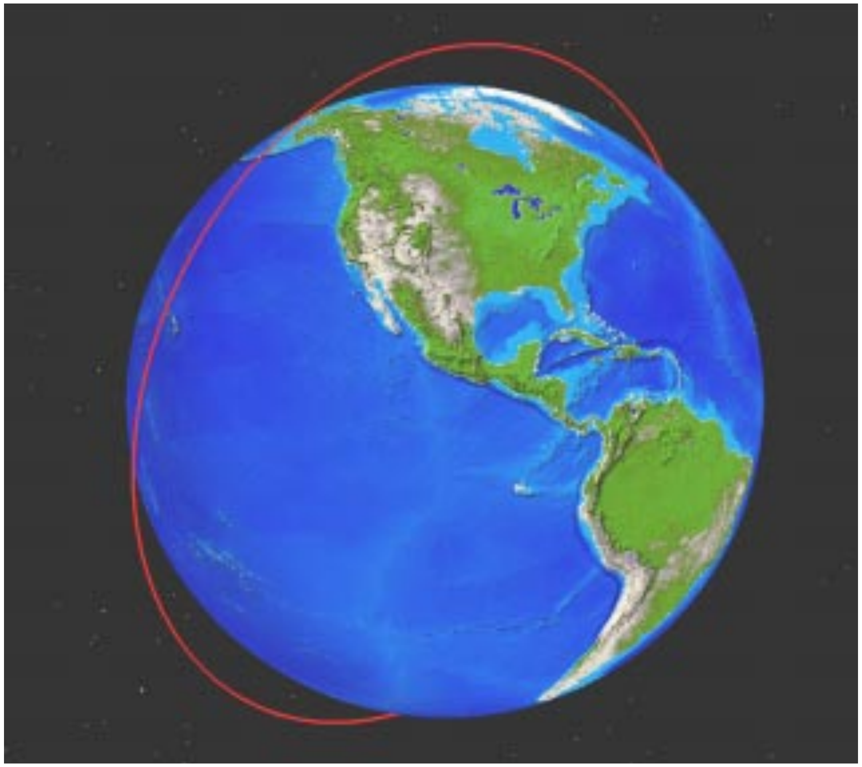
- Mumbo Jumbo
- Magic Sticks
- Soup to Nuts
- Chump Change
- Self Eating Watermelon
- Walking the Pig
- Like Presents Going Away Christmas Morning
- Pull Chocks
- Bark the Dog
- If You Want to Dance You Have to Pay for the Band

Orbits

Bernie Kelm

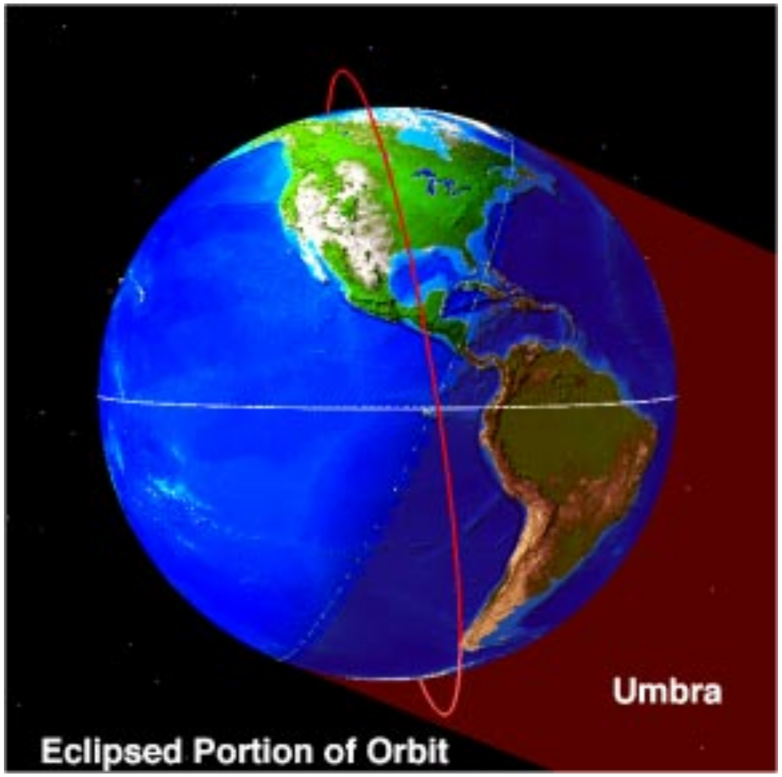
Orbit Selection

- Orbit Selected to Be 830 km Circular Orbit, Sun Synchronous Inclination
  - 101.5 Minute Period
- 6:00 PM Ascending Node Selected to Optimize Performance, Minimize Engineering Costs
  - Radiometry Will Work With Any Ascending Node
- Selected to Be in Similar Orbit As NPOESS/DMSP Orbits



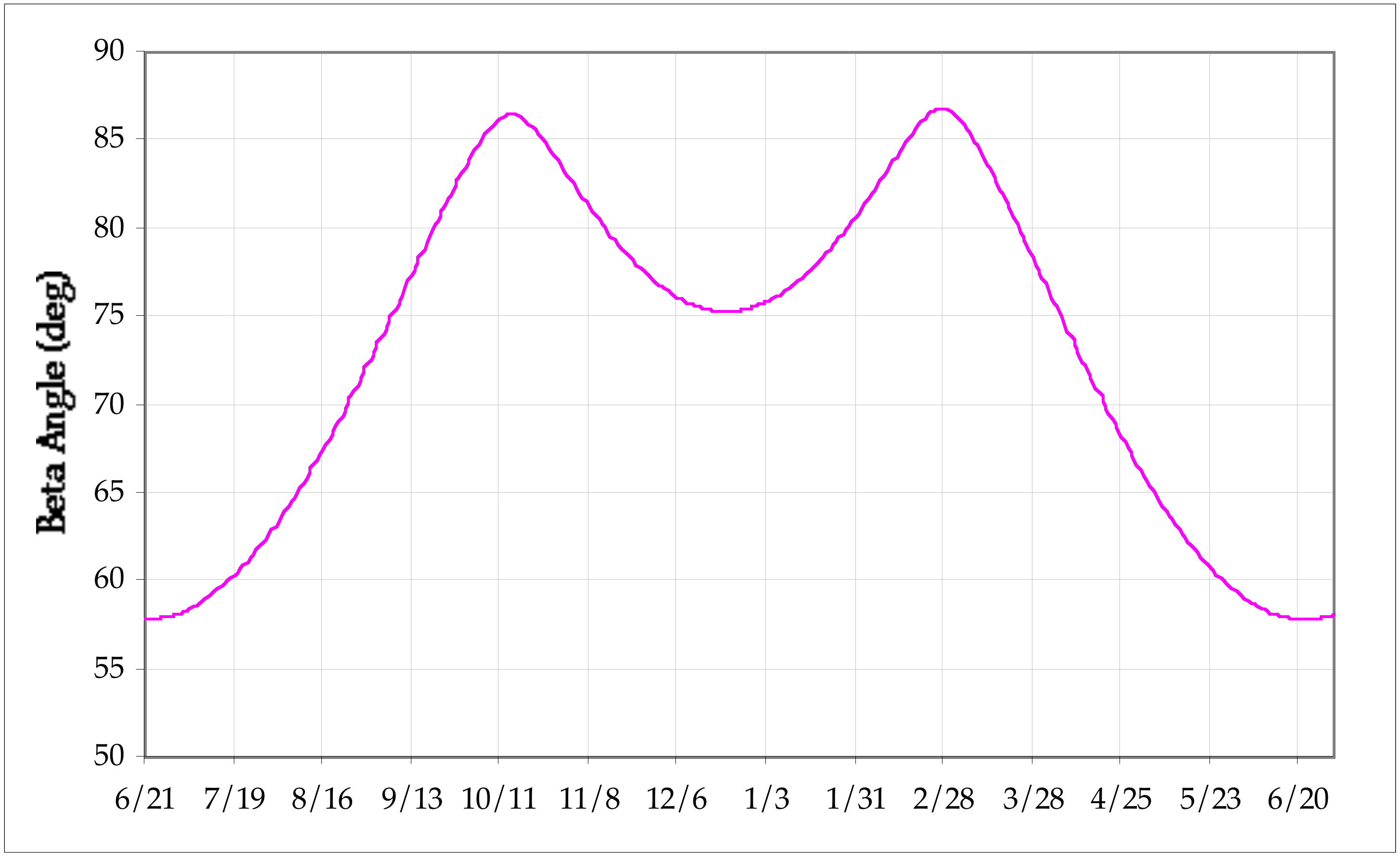
Eclipses

- 6:00 PM Ascending Node Selected to Minimize Eclipses
- Orbit Is Usually Full Sun
- Eclipse Season Occurs Once a Year
  - Eclipse Season Nominally Lasts for ~78 Days With Eclipses Occurring Every Rev
  - Maximum Eclipse Lasts for 17.7 Minutes, 17.4% of the Orbit



Sun Angle Variation

- **WindSat Beta Angles Vary Between 57° and 87° Over the Course of a Year**



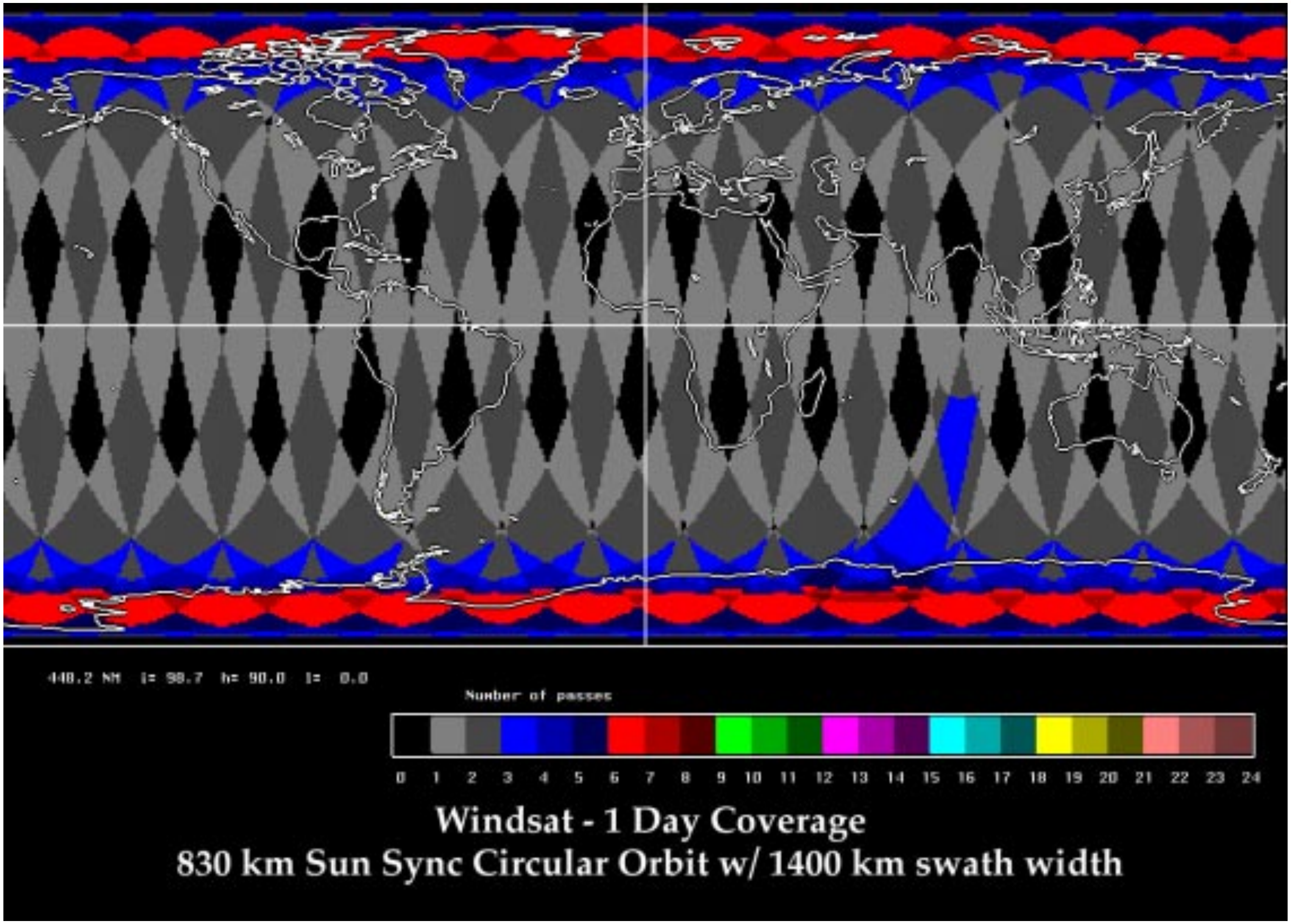
Long Term Orbit Behavior

- Semi-major Axis Decays 5 km Over 3 Year Mission
- Nominal Orbit:
  - Normally Full Sun. For a Period of ~78 Days, Occurring Once a Year in the Summer, Eclipses Occur Each Rev. Max Eclipse Period Is 17.7 Min. Eclipses Always Over Southern Hemisphere
  - Eccentricity Is Naturally Periodic and Grows to 0.0024, This Leads to 34.2 km Max Net Difference Between Apogee and Perigee Altitude
  - Long Term Inclination Changes are Minimal and Do Not Need to Be Maintained
- Orbit Decay Due to Drag and Long Term Periodic Changes of Orbit Are Acceptable for WindSat Mission
- Propulsion Not Needed to Maintain Nominal WindSat Orbit

Booster Insertion

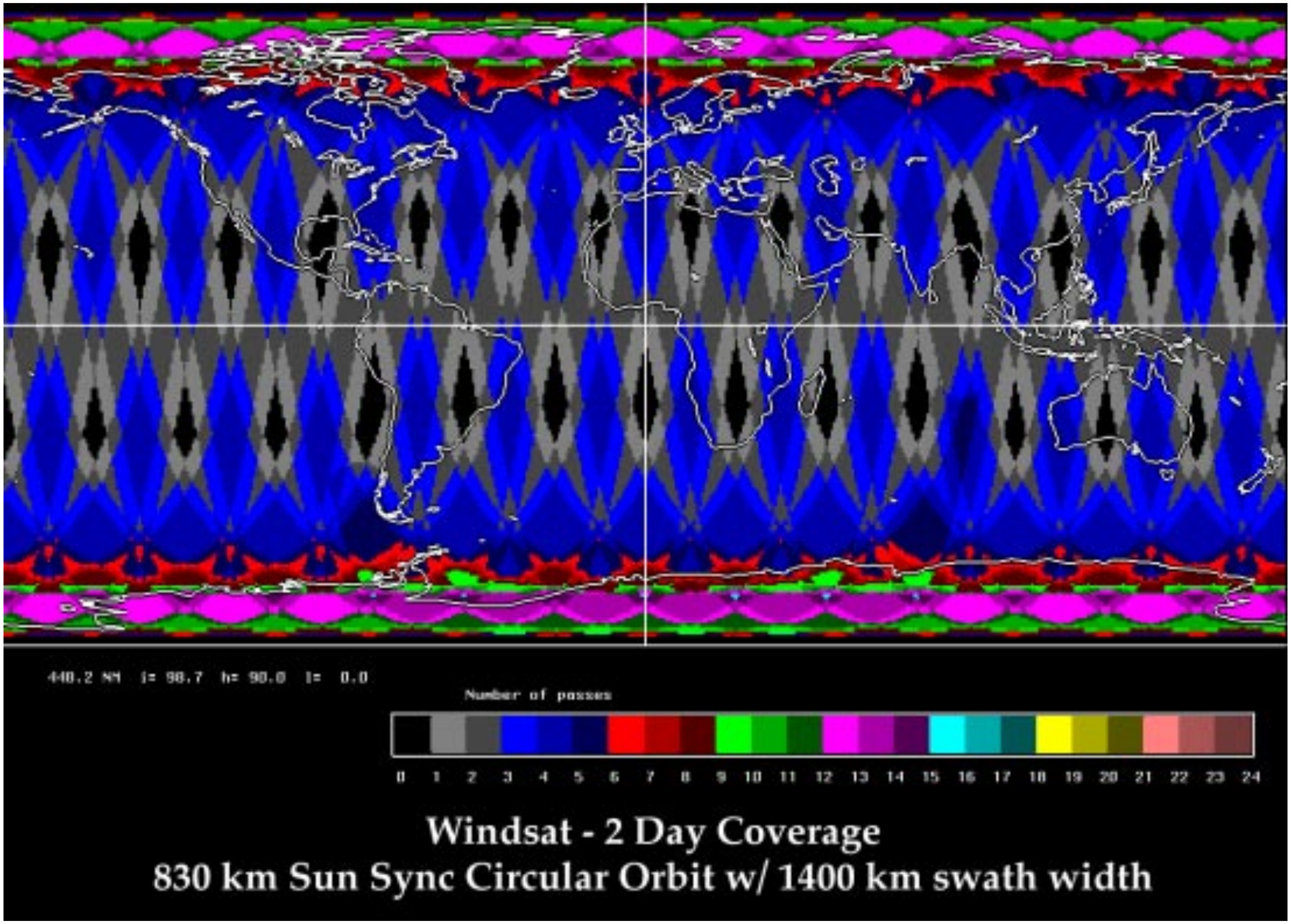
- **Titan II Insertion to 240 km by 830 km Sun Sync Orbit Would Require Additional Burns to Reach 830 km Circular**
  - **Maneuver Would Require 160 m/s of ΔV**
  - **Orbit Raising Maneuver Would Make Insertion Errors Negligible**
- **Backup Booster is Athena II**
- **Athena Orbit (830 Km Circular) Insertion Error of Inclination $\pm$0.1°, Altitude $\pm$ 20 Km:**
  - **Normally Full Sun - Winter Eclipse Period Originally Lasts for 78 Days, Grows to 101 Days at End of 3 Year Mission. Max Eclipse Is 17.2 Minutes the First Year, 18.5 Minutes the Second Year and 20.4 Minutes the Third Year. Eclipses Still Over Southern Hemisphere**
  - **Eccentricity Starts at 0.00277, Grows to 0.0038. This Yields a Max Net Difference in the Apogee/Perigee Altitude of 54.7 km**
  - **Athena II Insertion Errors are Acceptable for WindSat, Would Not Require Correction**

One Day Coverage



83.2% of the Earth Surface Covered in One Day

Two Day Coverage



93.0% of the Earth Surface Covered in Two Days
100% of the Earth Surface Covered in Four Days

WindSat System Performance Requirements

Peter Gaiser

WindSat Mission Science Goals

- Mission Science Goals Are Determined by the Capability of the WindSat System to Retrieve the Ocean Surface Wind Vector
  - Wind Speed ±2 m/s or 20% (whichever is greater)
  - Wind Direction ±20°
  - Wind Speed Range 3 – 25 m/s

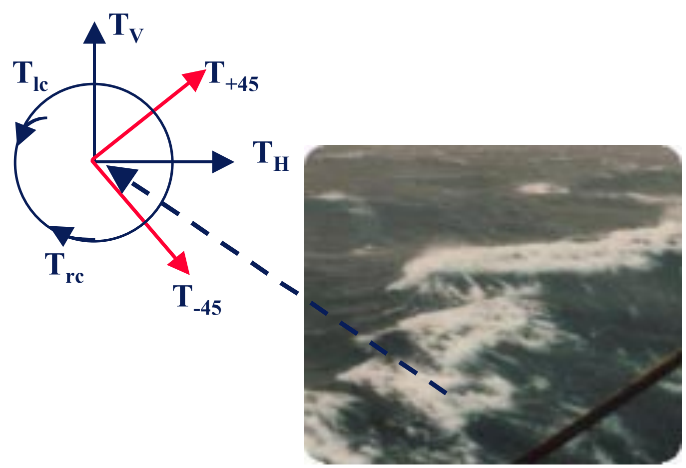
- Design of WindSat Payload to Meet Science Goals Results In a Sensor Capable of Retrieving Other Environmental Data Records (EDR)

- Secondary EDRs Do Not Drive the WindSat System Requirements

Polarimetric Radiometry

- **Ocean Surface Emission Varies With Wind Speed and <u>Direction</u>**
- **SSM/I <u>Wind Speed</u> Retrievals Are Being Used Operationally With Accuracy Better Than ±2 m/s**
- **Aircraft Measurements Have Shown That the <u>Wind Direction</u> Signal Is Measurable From 10–37 GHz at Broad Range of Wind Speeds**
- **Wind Direction Dependence Arises From Anisotropic Distribution and Orientation of Wind Driven Waves**
- **Polarimetric Radiometry Measures the Stokes Vector Which Describes the Polarization Properties of the Emitted Radiation**
- **Stokes Vector Contains Information Needed to Measure the Ocean Wind Vector**

$$I_s = \begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix} = \begin{bmatrix} T_v \\ T_h \\ T_{45} - T_{-45} \\ T_{lc} - T_{rc} \end{bmatrix} = \begin{bmatrix} \langle E_v E_v^* \rangle \\ \langle E_h E_h^* \rangle \\ 2\,\mathrm{Re}\langle E_v E_h^* \rangle \\ 2\,\mathrm{Im}\langle E_v E_h^* \rangle \end{bmatrix}$$

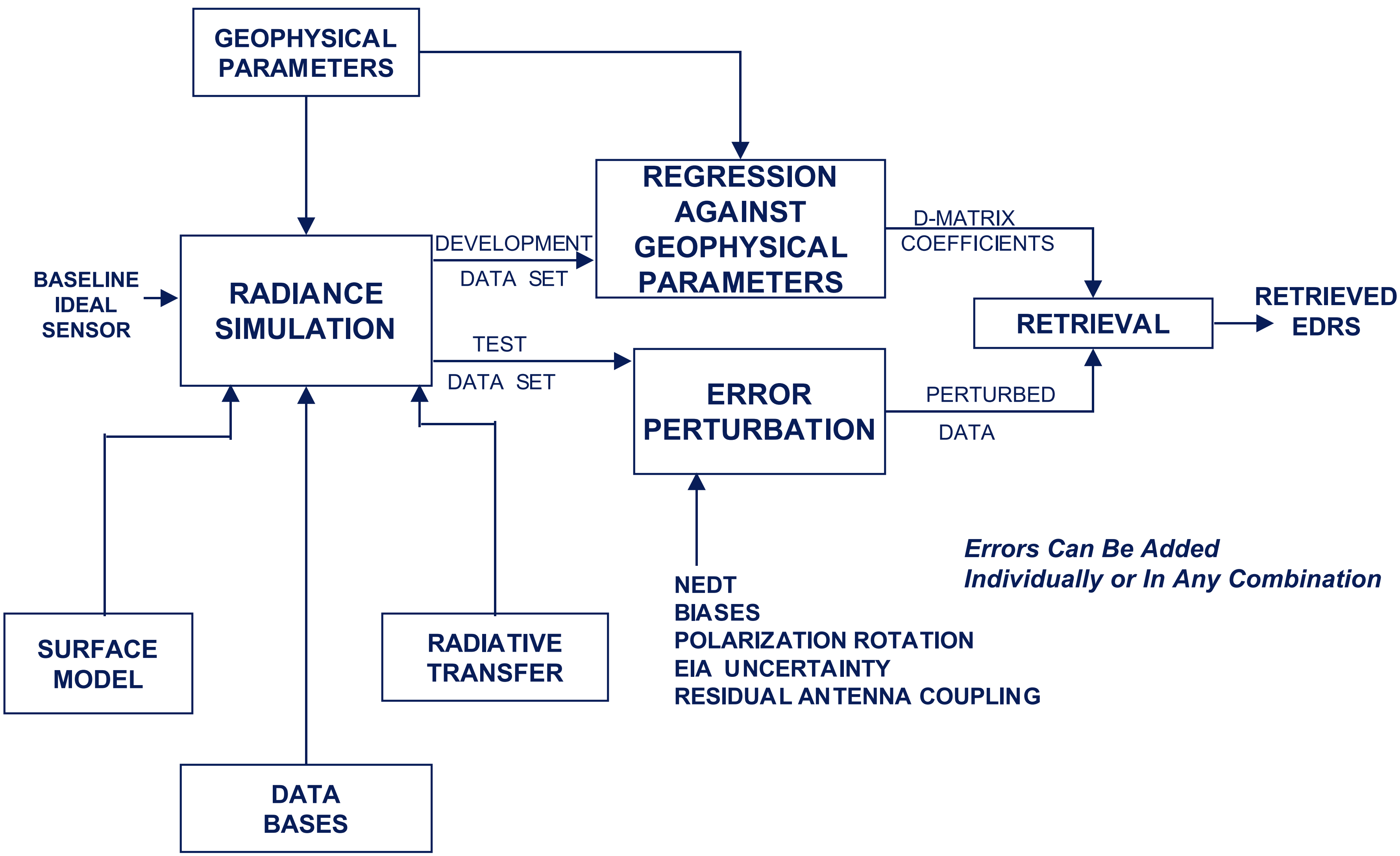


Smwave.jpg

Requirements Flowdown

- Radiometry Sensitivity Analysis Used to Derive All Key Performance Requirements
- Radiometer Simulation Generates Brightness Temperatures From Geophysical Parameters, Surface and Radiative Transfer Models
- Emissivity Uses Specular Plus Wind Roughened Surface
  - Hollinger Wave Effect Model for Isotropic Roughness
  - T_v and T_h Directional Variation Terms Derived From SSM/I Buoy Matchup Data Base
  - Third and Fourth Stokes Parameters (U, 4) Directional Dependence Modeled with NRL/JPL Aircraft Measurements
    - Validated by Buoys and Dropsondes
  - Foam Coverage Effects From Stogryn Model
- Tropospheric Water Vapor and Liquid Water Modeled with Van Vleck-Weisskopf

Sensitivity Analysis



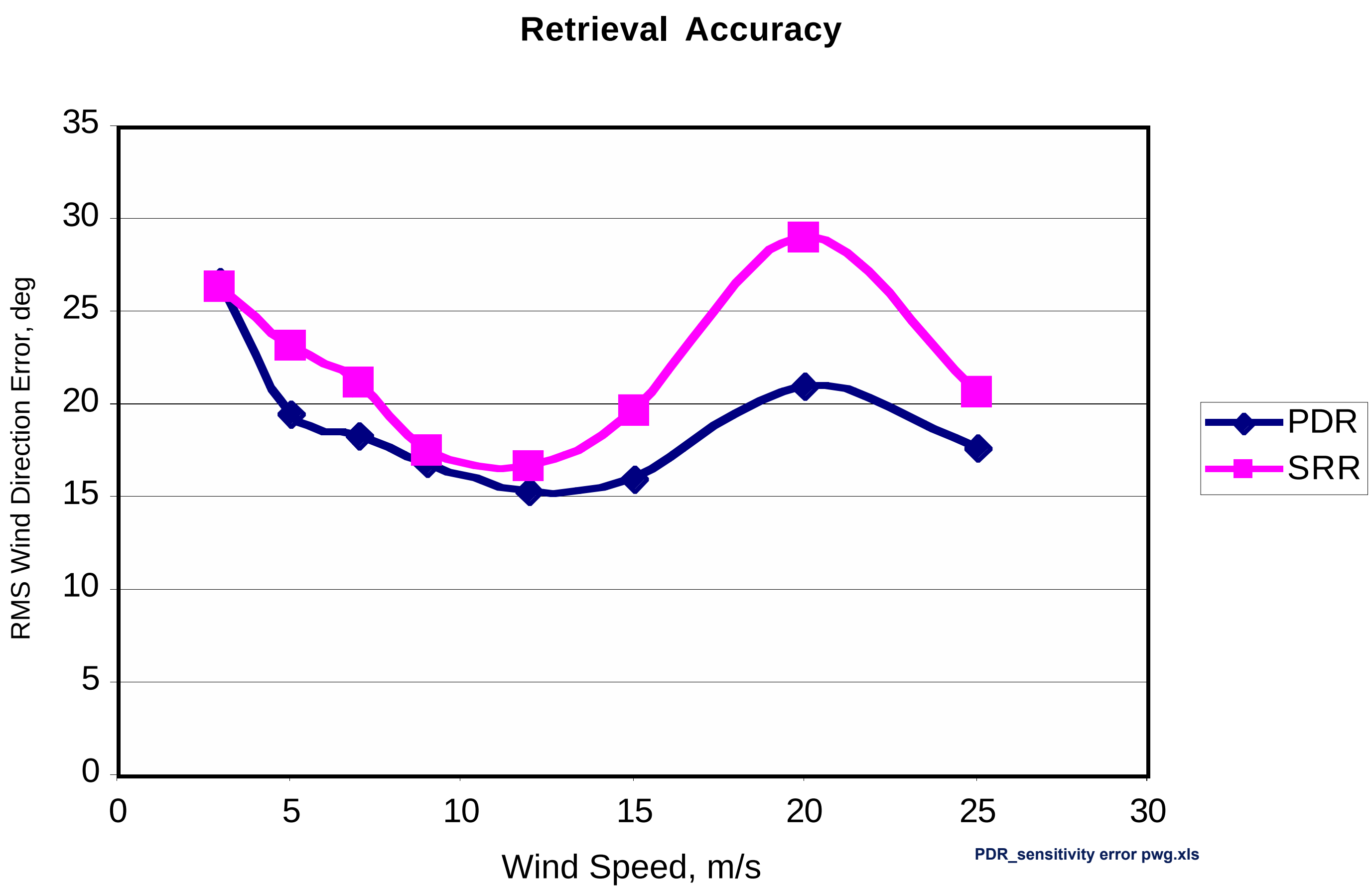
Model Performance

- Baseline Ideal Sensor
  - Fully Polarimetric at 10.7, 18.7 and 37 GHz
  - Dual Linear Polarization at 6.8 and 23.8 GHz
- Geophysical Parameters Included in Model
  - Wind Speed, Wind Direction, Sea Surface Temperature, Salinity, Water Vapor Mass, Cloud Water Mass
- Model Incorporates Uncertainties in Geophysical Parameters
- Arctic, Temperate and Tropical Atmospheres
  - Four Seasons
  - Clear and Cloudy
  - Non-Precipitating
- With Full Complement of System Errors and Global Conditions, Model Retrieves Wind Speed to Within ±1.4 m/s

Summary of Key Derived Requirements

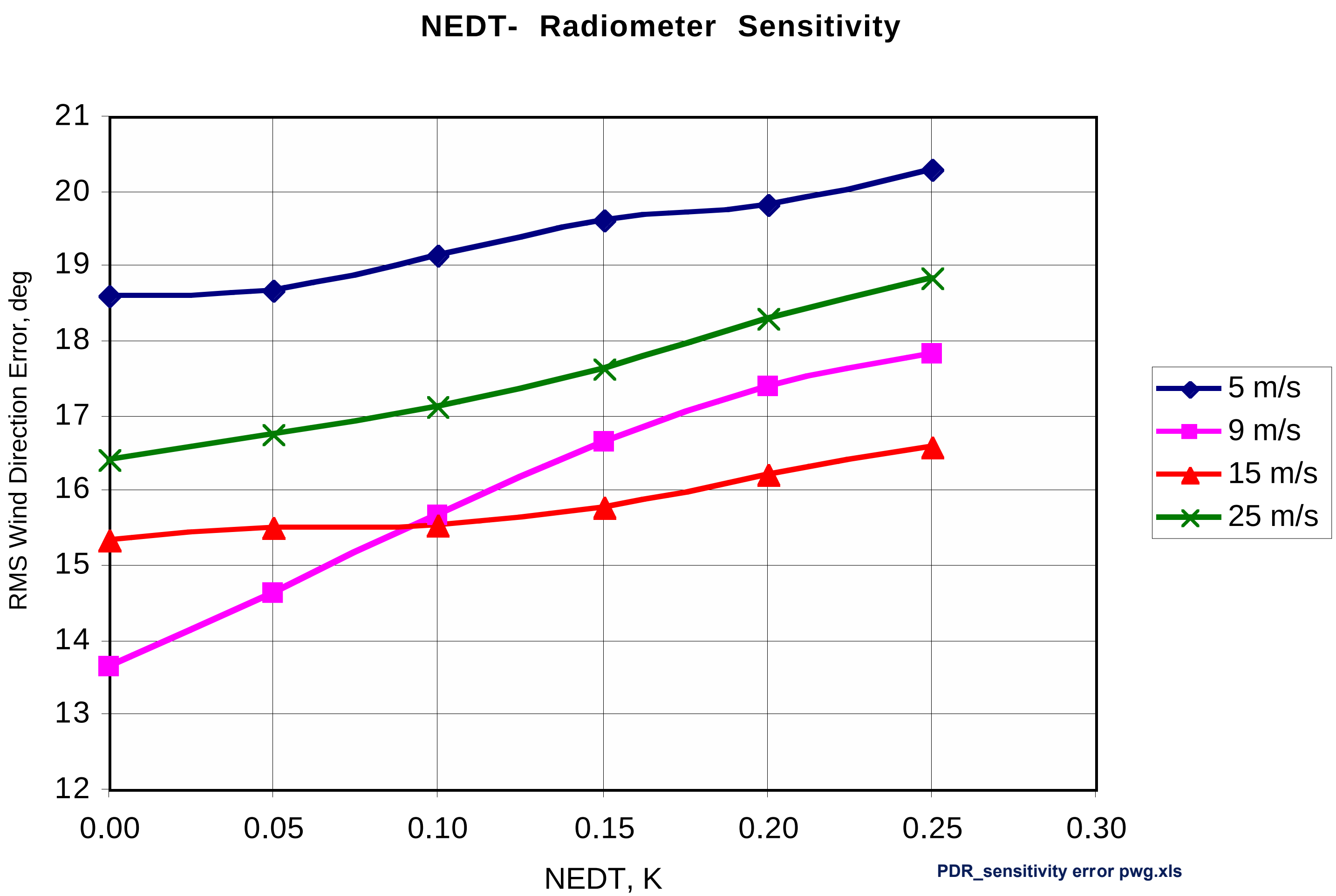
- NEDT - Receiver Noise (Each Single Polarization)
  - 6.8 — 0.20 K
  - 10.7 — 0.15 K
  - 18.7 — 0.15 K
  - 23.8 — 0.20 K
  - 37.0 — 0.10 K
- Calibration Biases
  - Linear Polarizations — 0.75 K
  - Polarimetric Channels — 0.25 K
- Residual Antenna Coupling
  - Linear Bands — 0.5% (-23 dB)
  - Polarimetric Bands — 0.1% (-30 dB)
- Polarization Rotation Knowledge — 0.05°/0.05° (Random/Bias)
- EIA Knowledge — 0.05°/0.05° (Random/Bias)

Wind Direction Retrieval Performance



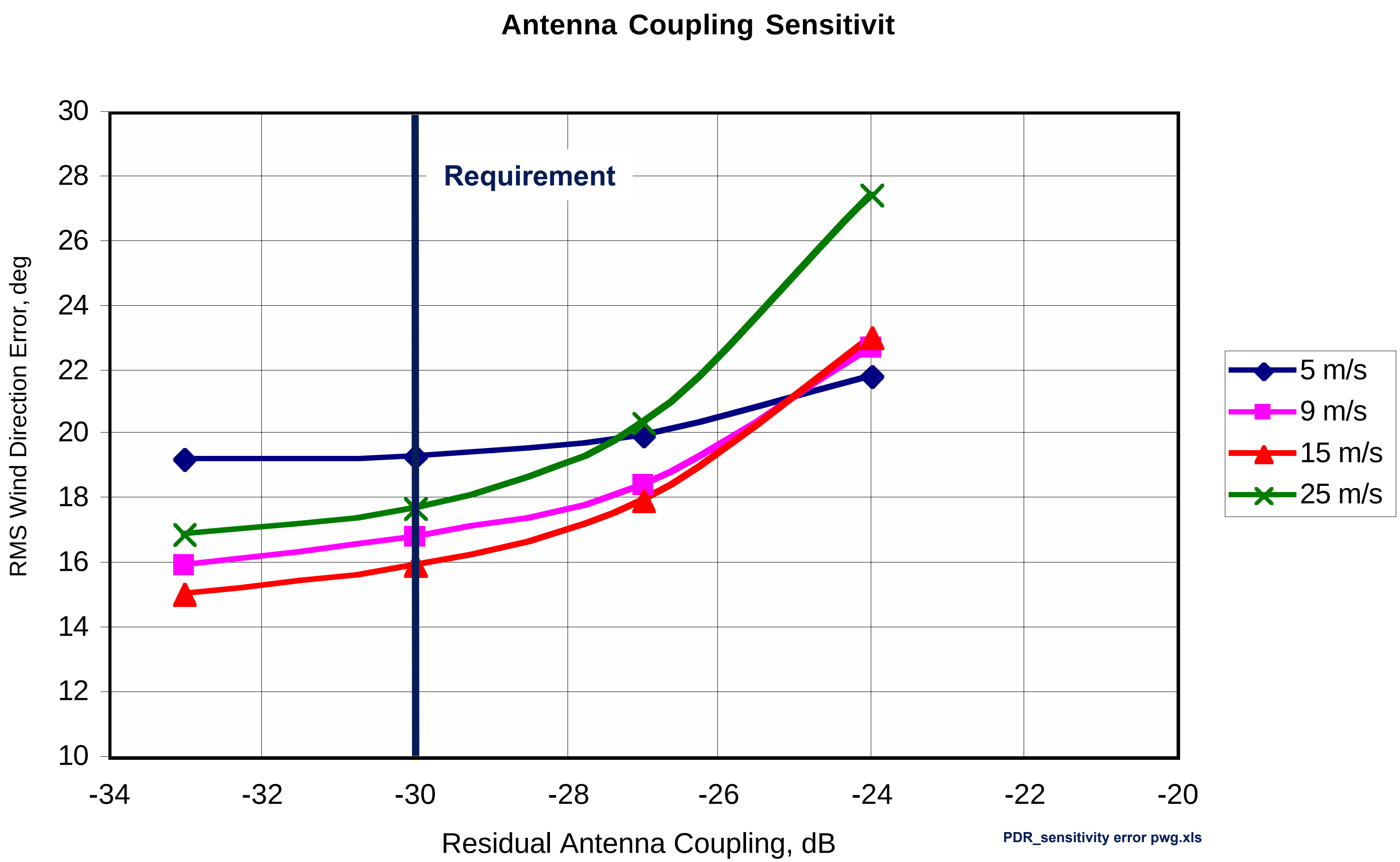
Inaccuracies Due to Environmental Noise and Sensor Errors (Design Requirements)
Single Look Retrieval

Wind Direction Sensitivity
NEDT - Radiometer Sensitivity

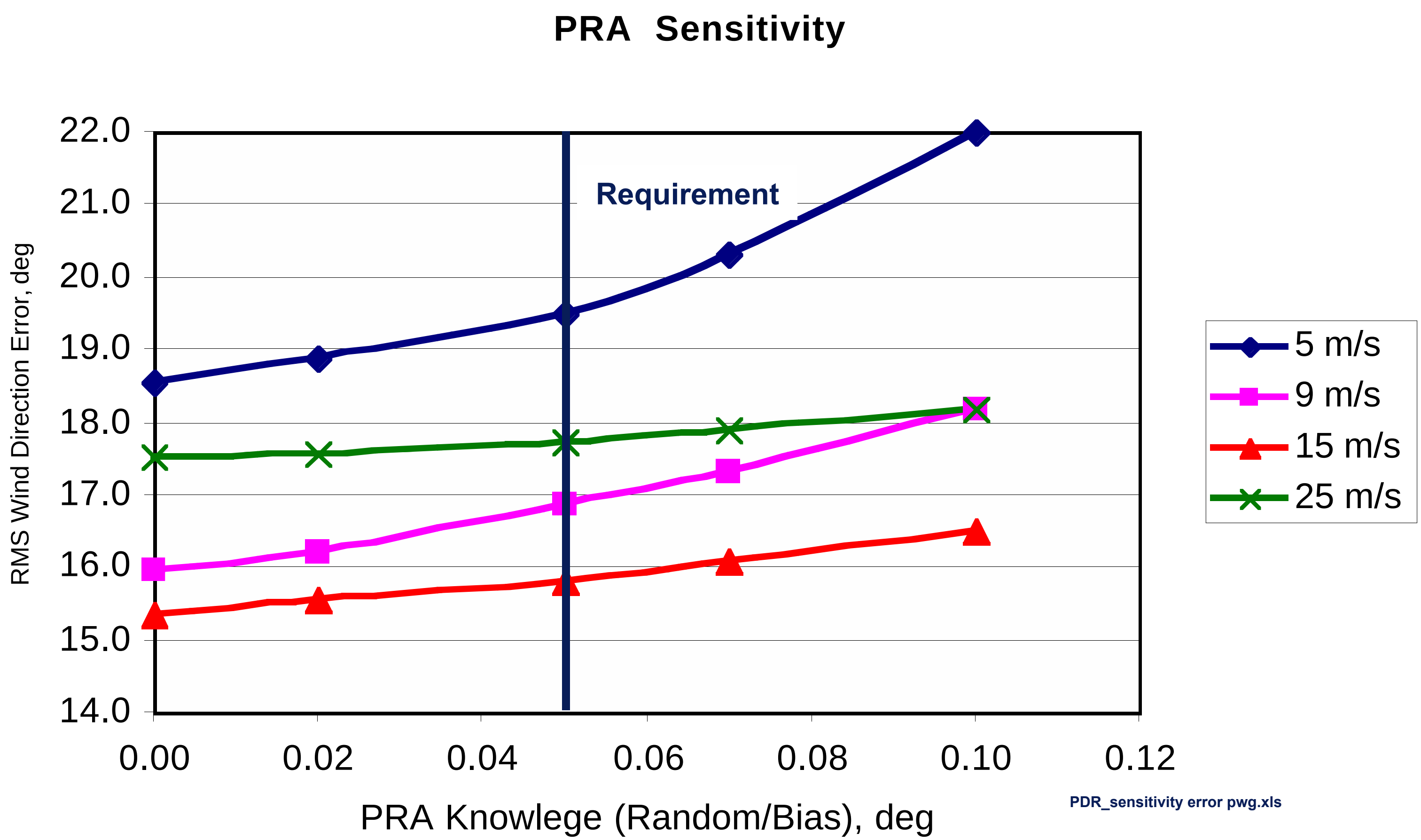


Assumes All Five Frequencies Have Same NEDT

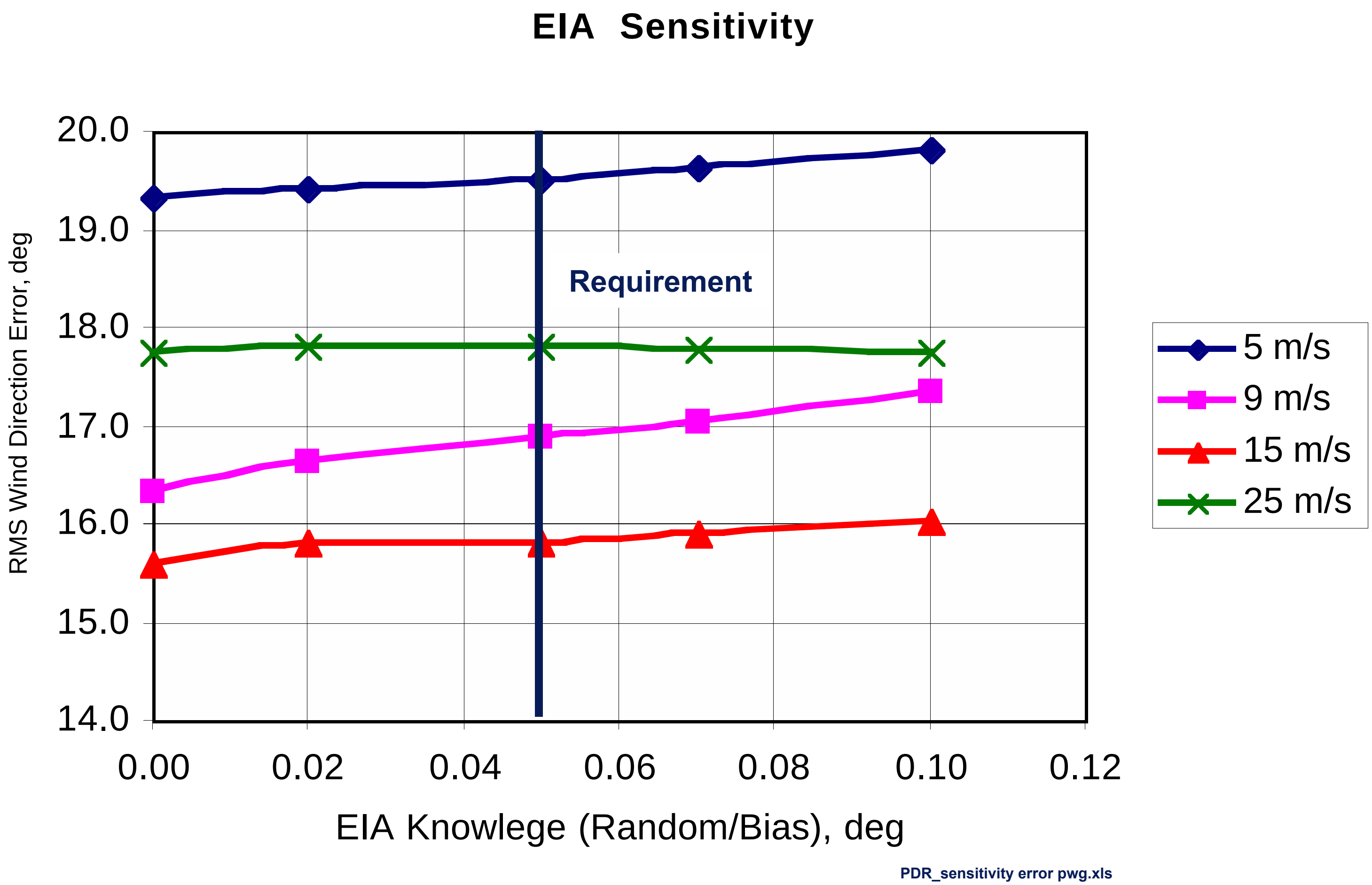
Wind Direction Antenna Coupling Sensitivity



Wind Direction Sensitivity
Polarization Rotation



Wind Direction Sensitivity
Earth Incidence Angle (EIA)



WindSat System
Requirements and Goals (1 of 3)

Radiometer

Freq, GHz	Polarization	BW, MHz	Absolute Accuracy, K	NEDT, K EFOV	Dynamic Range, K
6.8	V,H	125	0.75/0.25	0.20	3-330
10.7	V,H,U,4	200	0.75/0.25	0.15	3-330
18.7	V,H,U,4	500	0.75/0.25	0.15	3-330
23.8	V,H	500	0.75/0.25	0.20	3-330
37.0	V,H,U,4	2000	0.75/0.25	0.10	3-330

* 0.75 for single receiver channels (e.g., V, H); 0.25 for third and fourth Stokes parameters

WindSat System
Requirements and Goals (2 of 3)

Antenna

- Beam Efficiency – 95% for All Frequencies (Goal)
- Polarization Purity – Maximum Residual Coupling of -30 dB for Polarimetric Bands; -23 dB for Dual-Polarized Bands
- Horizontal Resolution – Goal to Achieve Effective Field of View As Close To NPOESS IORD As Possible. Currently ~ 30 km.
- Beam Coincidence – Must Be Able to Overlay Beams With Temporal Re-Registration and Beam Averaging
- Polarization Rotation Angle (PRA)
  - Knowledge of <0.05° Bias and Random
  - Alignment of ± 1° : Wide Range Acceptable Because of Robust Correction
- Earth Incidence Angle (EIA)
  - Nominal Fixed EIA In Range of 50°-55° – Consistent with NPOESS CMIS Concept, Aircraft Data, SSM/I Heritage
  - Knowledge of <0.05° Bias and Random
  - Maximum Variation of ~0.25°: Maintain Linearity of TB Variation With EIA

WindSat System Requirements and Goals (3 of 3)

Scan/Sampling

- Along Scan – Spatial Nyquist Sampling for All Frequencies
- Along Track – Contiguous Sampling of 37 GHz Pixels; Nyquist Sampling of Lower Frequencies
- Mapping Accuracy – Goal of 4 km (Half of 37 GHz Pixel)
- Scan Azimuth Angle – Control of < 0.15° To Ensure Repeatable Cold Calibration
- Fore and Aft Viewing – Necessary to Compare One-Look and Two-Look Wind Direction Retrieval Performance
- Swath – Maximum Possible Consistent with On-Orbit Calibration Requirements

Systems Engineering

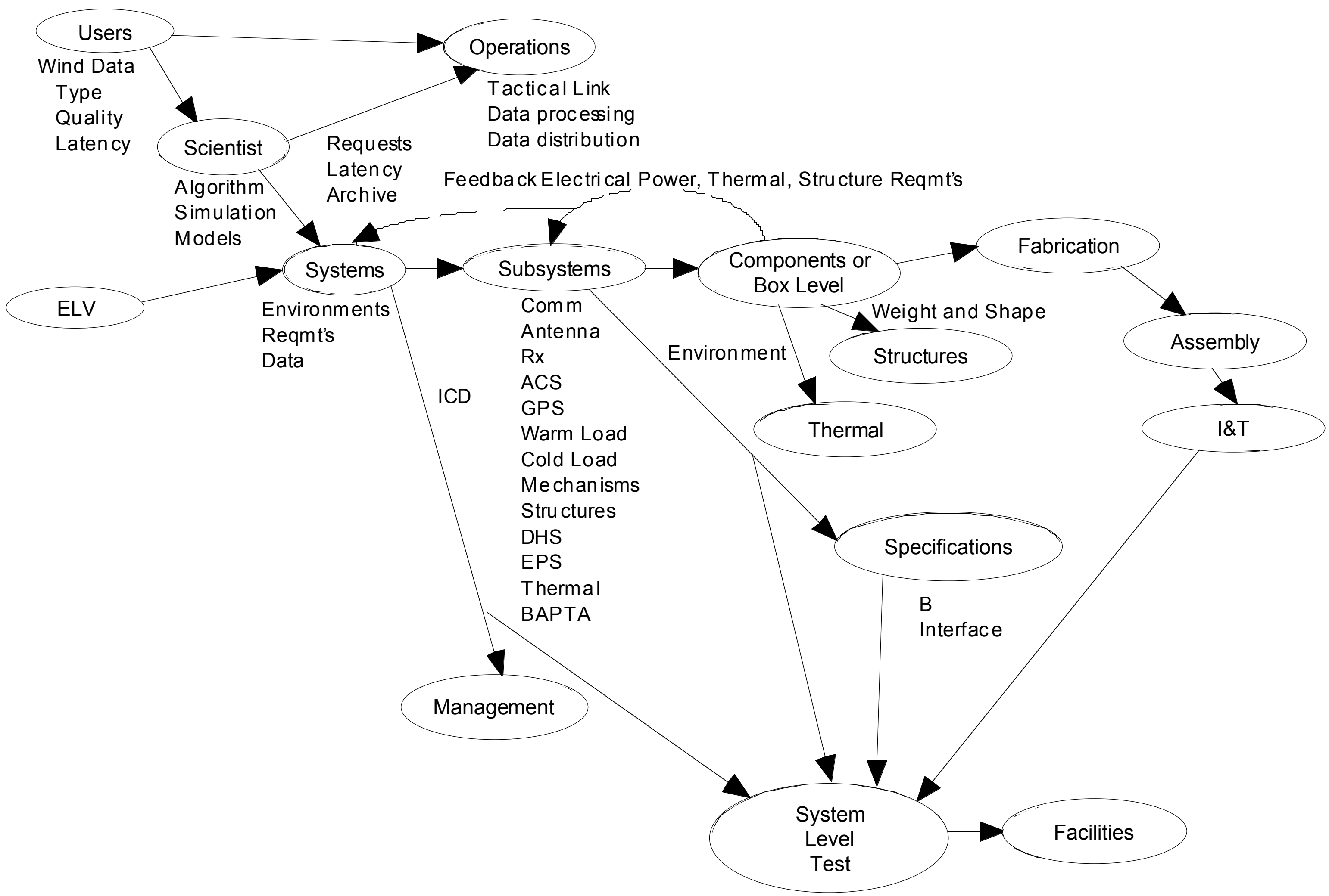
T. Gutwein

Summary Topics

- System Engineering Since SRR
- Subsystem Partitioning And Major Functional Interfaces
- PDR Level Subsystem Allocation Matrix
- Summary Level Error Budgets
- Key Derived Performance Requirements
- Payload Trade Studies Completed
- Summary Breadboard Results
- Command and Telemetry List
- Document Tree and Documentation Status
- System Analysis Trail/Memo Listing/Significance

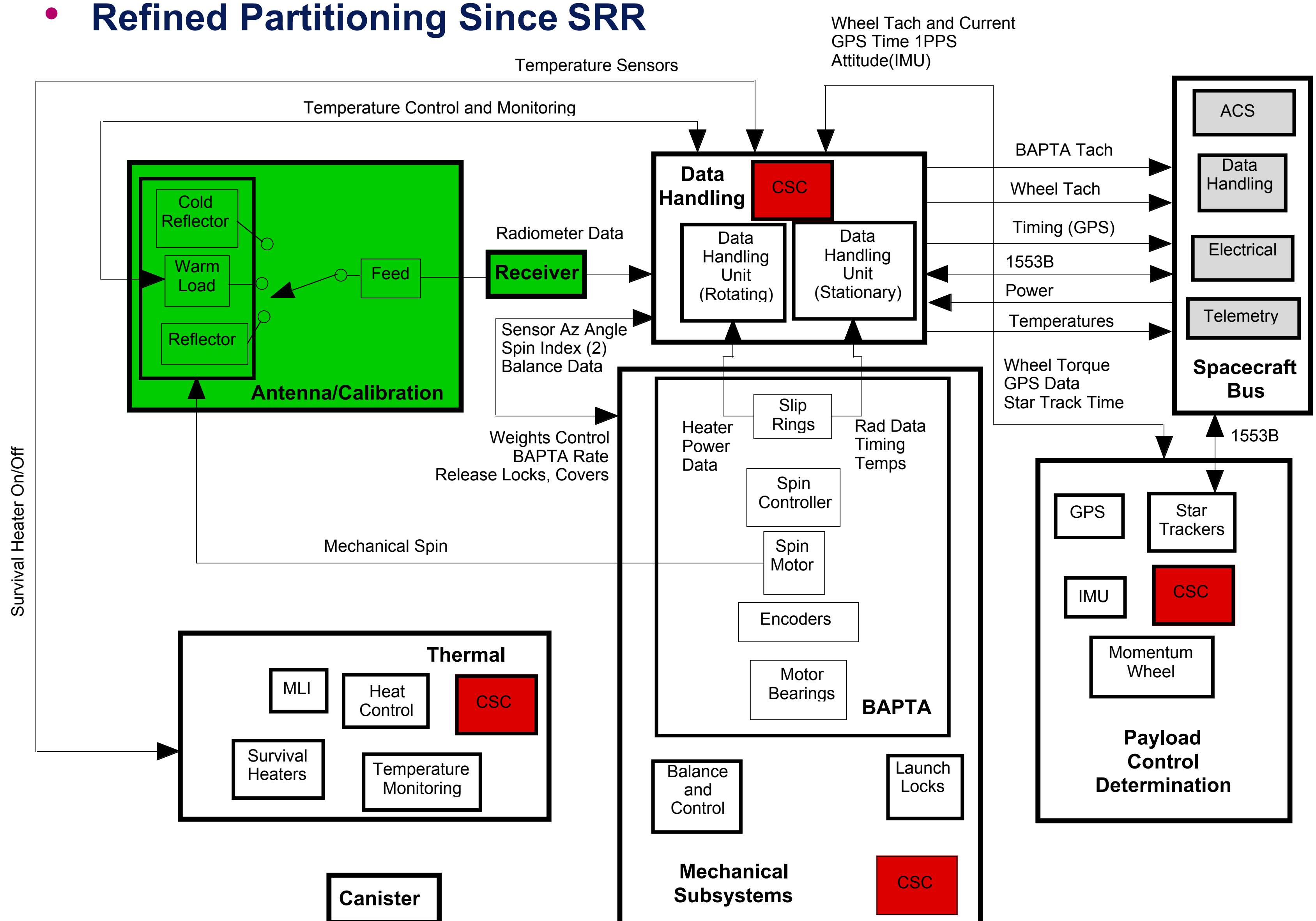
System Engineering Since SRR

- "Virtual" System Engineering Process Flow



Subsystem Partitioning/ Major Functional Interfaces

- **Refined Partitioning Since SRR**



Updated Subsystem Allocation Matrix

No	Subsystems	Type [1]	Pointing in deg [3] Control EIA [2]	Control VH [2]	Control SA [2]	Knowledge EIA	Knowledge VH	Knowledge SA	Scan 45 deg	EIA deg	Cal [4] Acc deg	Pol Pur dB	NEDT [4] K	# Freq [4]	# Looks	Beam Eff %	Hor Res Km	Pixel Geo Km	Swath Width	Wt #	Pwr watts
			Key System Requirements													**System Goals**					
			.25/1.0	1.0/1.0	0.10	.05/.05	.05/.05	0.03	0.80	50-56	.75/.25	30	0.2/0.1	2L/3P	2	95	20	4.0	Max	250	180
	Payload																				
1	**Antenna/Calibration Subsystem**	P,F,C	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2	Warm Load Cal	P,F,C			x			x			x	x		x	x				x	x	x
3	Cold Load Cal	P,F,C			x			x			x	x		x	x	x			x	x	x
4	Reflector	P,F,C	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
5	Feed	P,F,C	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
6	**Receiver Subsystem**	P,F,C			x			x				x	x	x				x		x	x
7	**Data Handling Subsystem**	P,F			x			x			x			x	x					x	x
8	**Mechanical Subsystems**	P,F,C	x	x	x	x	x	x	x	x	x		x	x						x	x
9	BAPTA	P,F,C			x			x					x	x						x	x
10	Spin Motor and Bearings	P,F,C	x	x	x	x	x	x	x	x										x	x
11	Slip Rings	P,F,C									x		x							x	x
12	Spin Controller	P,F			x			x												x	x
13	Encoders	P,F	x	x	x	x	x	x												x	x
14	Balance and Control	P,F,C	x	x	x	x	x	x												x	x
15	Launch Locks and Star Track Covers	C																		x	x
16	**Payload Control Determination**	P,F,C	x	x	x	x	x	x			x		x	x	x			x		x	x
17	GPS	P,F,C	x	x	x	x	x	x			x							x		x	x
18	IMU	P,F,C	x	x	x	x	x	x										x		x	x
19	Momentum Wheel	P,F,C	x	x	x	x	x	x										x		x	x
20	Star Trackers	P,F,C	x	x	x	x	x	x										x		x	x
21	**Thermal**	P,F,C	x	x	x	x	x	x			x		x							x	x
22	Survival Heaters	C																		x	x
23	Heat Control	F,C	x	x	x	x	x	x			x		x							x	x
24	Temperature Monitoring	P,F,C									x		x							x	x
25	MLI	C	x	x	x	x	x	x			x									x	x
26	**Canister**	C																		x	x
	Other Subsystems																				
27	**Spacecraft Bus**	P,F,C	x	x	x	x	x	x	x	x	x			x	x					x	x
28	ACS	P,F,C	x	x	x	x	x	x	x	x										x	x
29	Data Handling	P,F			x			x			x			x	x					x	x
30	Electrical	P,F																		x	x
31	Telemetry	P,F																		x	x
32	**Propulsion**	F,C																		x	x
33	**Flight Software**	F																			
34	**Ground**	P,F										x	x					x	x		
35	**Calibration**	P,F	x	x	x	x	x	x	x	x	x	x	x			x	x	x			

Notes:
1. Type of Requirement: P=Performance, F=Functional, C=Constraint
2. EIA=Earth Angle of Incidence, VH is EIA Plane Rotation About Antenna Boresight, Clock is Spin Angle About Nadir
3. Pointing Paired Values are Random/Bias Requirements
4. Calibration, NEDT, and # Frequency Paired Values Are Linear Channels/Polarimetric Channels Requirement

Summary Pointing Budget

• Refined And Systematic Changes Since SRR

01. Pointing System Level Requirements Budget Summary Totals	Budgetted		Required		% Margins	
	Bias	Random	Bias	Random	Bias	Random
01.04. Incidence Angle Control(EIA)	0.443	0.043	1.000	0.250	56	83
01.05. Incidence Angle Knowledge(EIA)	0.041	0.020	0.050	0.050	18	59
01.06. PRA Control	0.144	0.034	1.000	1.000	86	97
01.07. PRA Rotation Knowledge	0.035	0.019	0.050	0.050	31	63
01.08. SAA Control	0.077	0.034	0.150		26	
01.09. SAA Knowledge	0.032	0.018	na		na	
01.10. Normal to Scan Geolocation Error Bias + Noise	0.047		0.070		33	
01.11. Along Scan Geolocation Error Bias + Noise	0.050		0.070		28	
01.12. Rate Control/Jitter Normal to Scan	0.035		0.070		50	
01.13 Rate Control/Jitter Along Scan	0.042		0.070		40	
01.14 SA Calibration Scan Angle Control	0.015		na		na	

EIA=Earth Incidence Angle PRA=Polarization Rotation Angle SAA=Sensor Azimuth Angle

Notes:

1. All Values in degrees
2. Geolocation Requirement Based on 1/5 of a Beamwidth At 37 GHz
3. Single Entries Represent Sum of Bias and Noise Errors
4. Items 01.01, 01.02, 01.03, and 01.14 are Subtotal Components For Budget Tracking as Shown Below:

	A. Budgetted EIA		B. Budgetted PRA		C. Budgetted SAA	
	Bias	Random	Bias	Random	Bias	Random
01.01. Antenna Boresight Knowledge EIA Error in deg	0.020	0.010	0.026	0.015	0.020	0.010
01.02. Antenna to Bench EIA Knowledge Error in deg	0.007	0.002	0.007	0.002	0.012	0.010
01.03. Attitude Determination EIA Knowledge Error in deg	0.021	0.011	0.021	0.011	0.021	0.011

	PRA	Nadir	SAA
01.14. Antenna Boresight Errors in deg	0.024	0.018	0.018

Allocated a Data Handling Synchronization SAA of 0.002 deg As an Insignificant Percentage Of Total 0.15 deg Pointing Requirement
Basis of Estimate is a 10 microsecond Resolution Out Of A 2 Second Spin Period

Allocation Of Pointing Budgets To Subsystems(SRR Version):

	Impacted Subsystems								
Bias	Antenna	Ephemeris	ACS	Orbit Error (RCS)	Geoid	Antenna/ Bench	Spin	Data Handling	Allocation
01.04. Incidence Angle Control(EIA)	0.020	0.000	0.200	0.400	0.000	0.010			0.448
01.05. Incidence Angle Knowledge(EIA)	0.020	0.003	0.030	0.000	0.001	0.010			0.038
01.06. PRA Rotation Control	0.020	0.000	0.150	0.000	0.000	0.010			0.152
01.07. PRA Rotation Knowledge	0.020	0.002	0.020	0.000	0.000	0.010			0.030
01.08. SAA Spin Rotation Control	0.020	0.000	0.070	0.000	0.000	0.020	0.080	0.000	0.110

Allocation Of Pointing Budgets To Subsystems(SRR Version):

	Impacted Subsystems								
Random	Antenna	Ephemeris	ACS	Orbit Error (RCS)	Geoid	Antenna/ Bench	Spin	Data Handling	Allocation
01.04. Incidence Angle Control(EIA)	0.015	0.000	0.040	0.000	0.000	0.003			0.043
01.05. Incidence Angle Knowledge(EIA)	0.015	0.003	0.015	0.000	0.001	0.003			0.021
01.06. PRA Rotation Control	0.015	0.000	0.030	0.000	0.000	0.002			0.034
01.07. PRA Rotation Knowledge	0.015	0.002	0.010	0.000	0.000	0.002			0.018
01.08. SAA Spin Rotation Control	0.010	0.000	0.030	0.000	0.000	0.000	0.005	0.002	0.032

Sheet 1 Summary Level Pointing Compliance Table
Sheet 2 Antenna Alignments and Attitude Sensor Budgets
Sheet 3 Incidence Angle Control and Knowledge Budgets
Sheet 4 Boresight Rotation or V/H, or PRA Control and Knowledge Budget
Sheet 5 Clock, or Nadir, or SAA Control and Knowledge Budget
Sheet 6 Geolocation Error
Sheet 7 Antenna Boresight Errors

Antenna Polarization Budget

- **Polarimetric Channels**

02. Antenna Polarization Purity

	Unperturbed Average Poe Code dB		Range Purity For 30 dB Residual dB	Worst Case Intervals For 30 dB			
	U	V		U 30 dB Plus	U 30 dB Minus	V 30 dB Plus	V 30 dB Minus
02.01. 10.7 GHz	-30.99	-41.51	-57	-30.56	-31.43	-40.16	-43.10
02.02. 18.7 GHz	-34.10	-44.90	-57	-33.50	-34.75	-42.97	-47.38
02.03. 37 GHz	-36.74	-45.93	-57	-35.94	-37.63	-43.78	-48.77

02.04 Range Error Budget To Meet 30 dB Calibration Residual

Item	Performance Parameter	Value	Units	Contribution
1	Orthomode Isolation	-65.000	dB	-65.00
2	Ground Reflections	-70.000	dB	-70.00
4	Source Antenna Pol Purity	-65.000	dB	-65.00
5	Encoder	0.001	degree	-95.16
			RSS in dB	-61.35
			Worst Case Requirement in dB	-57.00
			Range Margin in dB	4.35

- **Non-Polarimetric Channels Require 23 dB - Relaxation from 30 dB at SRR**

NEDT Summary Budget

- **Minor Noise Figure and Loss Changes Since SRR**

	Random			Ground				
03. NEDT System Level Summary Budgets	**Ant**	**Rx**	Total RSS	Int Beams	EFOV	Requirement	Margin	%Margin
03.01. 37 GHz	0.085	0.385	0.394	20	0.088	0.100	0.012	11.8
03.02. 23.8 GHz	0.060	0.483	0.487	10	0.154	0.200	0.046	23.1
03.03. 18.7 GHz	0.047	0.421	0.424	10	0.134	0.150	0.016	10.7
03.04. 10.7 GHz	0.037	0.409	0.411	10	0.130	0.150	0.020	13.4
03.05. 6.8 GHz	0.053	0.412	0.415	10	0.131	0.200	0.069	34.3

Subsystem Losses as Impacting NEDT:

Subsystem	**6.8**	**10.7**	**18.7**	**23.8**	**37**	**Assumptions**
Antenna						
Horn Loss	0.02	0.03	0.06	0.07	0.11	Linear with Freq
OMT Loss	0.02	0.03	0.06	0.08	0.12	Linear with Freq
Transmission Loss	0.02	0.03	0.05	0.06	0.09	Linear with Freq.
Isolation	0.01	0.01	0.01	0.01	0.01	Isolation= 25
VSWR Mismatch	0.02	0.02	0.02	0.02	0.02	VSWR= 1.15
Subtotal Antenna Pre LNA Loss	0.10	0.13	0.20	0.24	0.35	
Allocated Antenna Loss	0.30	0.30	0.30	0.30	0.40	
Antenna Subsystem Loss Margin in %	68	58	34	20	11	
Receiver						
Pre LNA Losses	0.50	0.15	0.18	0.18	0.18	Isolator +Trans Line
Subtotal Rx Pre LNA Loss	0.50	0.15	0.18	0.18	0.18	
Total Radiometer Pre LNA Losses	0.60	0.28	0.38	0.42	0.53	

Allocated Subsystem Budgets

	Impacted Subsystems							
	Random			**Ground**				
03. NEDT Summary Allocations	**Ant**	**Rx**	Total RSS	Int Beams	EFOV	Requirement	Margin	%Margin
03.01. 37 GHz	0.060	0.417	0.421	20	0.094	0.100	0.006	6
03.02. 23.8 GHz	0.060	0.602	0.605	10	0.191	0.200	0.009	4
03.03. 18.7 GHz	0.060	0.444	0.448	10	0.142	0.150	0.008	6
03.04. 10.7 GHz	0.060	0.444	0.448	10	0.142	0.150	0.008	6
03.05. 6.8 GHz	0.060	0.602	0.605	10	0.191	0.200	0.009	4

Basis of Allocation is a Scene Temperature of 250 K

BER of Data Handling, Slip Rings, and Communications Subsystems is Insignificant

Beam Efficiency Summary Budget

- **Major Impact Since SRR Is X-Polarization and Strut Impacts**

04. Beam Efficiency Summary Budgets

04.01 37 GHz Beam Efficiency

Contributor	37 GHz				
	Parameter		Efficiency Impacts		
	Value	Units	Random	Bias	Total
Reflector Roughness	5	mils rms		96.21	96.21
Feed Phase	1	deg rms		99.88	99.88
2.5 Beamwidths Mainbeam	26	dB taper		99.24	99.24
Crosspolarization	26	dB		99.10	99.10
Struts	24-1.5"	Al/round		99.57	99.57
				Total	94.10
				Goal	95.00
				Margin	-0.90
				% Margin	-1

04.02 18.7 GHz Beam Efficiency

Contributor	18.7 GHz				
	Parameter		Efficiency Impacts		
	Value	Units	Random	Bias	Total
Reflector Roughness	5	mils rms		99.02	99.02
Feed Phase	1	deg rms		99.97	99.97
2.5 Beamwidths Mainbeam	26	dB taper		99.24	99.24
Crosspolarization	26	dB		99.10	99.10
Struts	24-1.5"	Al/round		99.57	99.57
				Total	96.93
				Goal	95.00
				Margin	1.93
				% Margin	2

04.03 10.7 GHz Beam Efficiency

Contributor	10.7 GHz				
	Parameter		Efficiency Impacts		
	Value	Units	Random	Bias	Total
Reflector Roughness	5	mils rms		99.68	99.68
Feed Phase	1	deg rms		99.99	99.99
2.5 Beamwidths Mainbeam	26	dB taper		99.24	99.24
Crosspolarization	26	dB		99.10	99.10
Struts	24-1.5"	Al/round		99.57	99.57
				Total	97.59
				Goal	95.00
				Margin	2.59
				% Margin	3

Absolute Accuracy Summary Budget

- **Values Revised Since SRR**

05. Absolute Accuracy

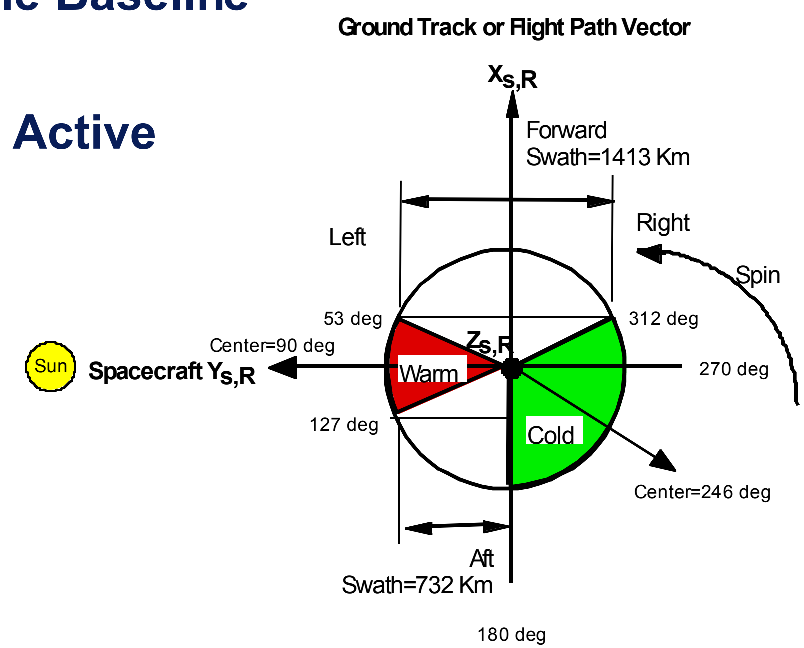
	05.xxA=Stokes I/Q Rows						05.xxB=Stokes U/V Rows					
	Predicted		Allocated		% Margins		Predicted		Allocated		% Margins	
	Bias	Noise	Bias	Noise	Bias	Noise	Bias	Noise	Bias	Noise	Bias	Noise
05.01 Warm Load I/Q			-0.15	0.15			n/a	TBR	n/a	0.10	n/a	TBR
05.02 Cold Load I/Q			0.40	0.15			n/a	TBR	n/a	0.15	n/a	TBR
05.03 Receiver Nonlinearities			-0.50	0.10			n/a	TBR	n/a	0.10	n/a	TBR
05.04 Antenna Beam Efficiency			n/a	0.15			n/a	TBR	n/a	0.15	n/a	TBR
05.05 Receiver Gain Drift			n/a	0.06			n/a	TBR	n/a	0.06	n/a	TBR
Totals	TBR		0.69				TBR		0.21			
Required	0.75		0.75				0.25		0.25			
Margin in K			0.06						0.04			
Margin in %			8						16			

Swath Summary Budget

- **Asymmetrical Favoring Forward Swath**
- **Swath Geometry Revisions Have Included**
  - **Warm Load Angular Interval From +/- 30 degree to +/- 37 degree**
  - **Primary Offset From 5 to 8 inch**
  - **Spin Axis From 15 to 18 inch**
- **Basis For Cold Load Boresight Generally Away From Sun**
- **Maximizing Forward Swath For Experiment With Available Swath For Aft Swath 2-Look Experiment is The Baseline**
- **CCW From Above Spin As Shown**
- **Allocation to Subsystems Is Based on Active Calibration Intervals**

06.03 Cold Aft Blockage 18 Inch and 5 deg Boresight= 90 deg

	A		**B**	
	Forward		**Aft**	
Contributor	**Right**	**Left**	**Right**	**Left**
Cold Reflector Sector in deg	42		90	
Warm Load Sector in deg		37		37
Guard	0	0	0	0
Sensor Quadrant Allocation in deg	48	53	0	53
Sensor Forward and Aft Allocation in deg	**101**		**53**	
Sensor Swath in Km	**1413**		**732**	



View Toward Earth Nadir

Key Derived Performance Requirements

- Optimize Feed Pointing For Polarization Performance
- Feed Pointing Plus Feed Taper for Beam Efficiency
- Receiver Linearity For Calibration Accuracy
- Polarimetric Thermal Uniformity For Common Mode Performance
- Two Integration Period Synchronizations Per Spin for Calibration Repeatability
- Feed/receiver Isolation As Impacting Calibration Bias Greater Than 60 dB (VSWR and Isolation)
- RF Radiation Coupling Into Polarimetric Bands to Minimize Calibration Errors
- OMT Isolation For Range Versus Orbit (40 dB and Phase Relationships)
- Polarimetric Channel Triplet Coalignment in EIA to Better Than 0.02° for Retrieval Accuracy
- Warm Load Temperature Uniformity for Calibration Accuracy

WindSat
Payload Trade Studies Completed (1 of 3)

- Reflector Material
  - Selected Composite - Performance - Thermal Stability
- Reflector Deployment
  - Deployed vs Rigid
  - Non-Deployed (Rigid) Selected
  - Alignment Requirement and Cost
- Reflector Truss
  - Composite vs Metal
  - Selected Composite - Angular Momentum
- Antenna Test Range
  - Develop Range From Surplus Assets
  - Performance/Cost
- Canister Structure
  - Composite vs Metal
  - Selected Metal - Cost

WindSat
Payload Trade Studies Completed (2 of 3)

- Thermal Control
  - Capillary Pump Loops vs Heat Pipes
  - Selected Heat Pipes - Cost
- Pointing Determination and Control
  - Payload vs Spacecraft
  - Payload - Selected Momentum Cancellation, Balance Mechanism, GPS
    - Obtained Surplus Momentum Wheel From BMDO
  - Spacecraft - Star Tracker's and Internal Reference Units
  - Cost / Complexity
- Slip Rings
  - Roller, Brush, Fiber
  - Selected Brush - Performance
- Subsystem
  - Make / Buy / Vendor Selection

WindSat
Payload Trade Studies Completed (3 of 3)

- 5 Feeds With Polarization Combining Receivers vs. 11 Feeds With Dual Channel Receivers
  - Selected 11 Feeds - Receiver Simplicity
- Data Compression - Yes/No
  - Selected On-Orbit Compression - Improved Data Flow
- Centralized vs Distributed Receiver Power
  - Distributed Power Selected to Improve EMI/EMC Performance
- Analog vs Digital Integration
  - Analog Selected Because of Heritage and Lower Clock Rates

Summary Breadboard Results

- Antenna (Reflector and Feed)
  - 10.7 GHz Range Data Obtained
  - Range Polarization Purity Validated At Better Than -70 dB
  - Breadboard 10.7 GHz Corrugated Horn/OMT Isolation Validated At Better Than -65 dB
  - Poe Code Tool for Polarization Processing Completed

- Receiver
  - Linearity Measurements Of LNA Over -30 C to +60 C Dynamic Range Are Within Budgeted Values
  - Output Load Matching Used to Obtain Linearity Performance
  - Dual Channel Linearity Meets Requirements

Command and Telemetry List
(1 of 3)

Rotating Side	Commands					Telemetry			
	Discrete		Digital			Digital		Analog	
Component	Pwr Relay Count	Other Relay Count	Bi-Level Count	Pulsed Count	Serial Count	Bi-Level Count	Serial Count	Voltages Count	Temp Count
Antenna/Calibration Subsystem									
Reflector Structure									10
Reflector									5
Horn/OMT(11 Feeds)									
Receiver Subsystem(5 boxes)									
LNAs								2 **	22 **
DEU	5 *					5 *		5 **	11 **
REU					5		5	1 **	11 **
Data Handling Subsystem									
Rotating DHU (RDHU)								4	1
Mechanical Subsystems									
BAPTA									1
Spin Balance Control	1 *				1 *	1 *	1 *	4	1
PCD Subsystem									
GPS Antenna									1
GPS Receiver	1 *				1 *	1 *	1 *		1
Thermal Subsystem									
Heat Pipes									4
Payload Heaters									
Canister Subsystem Structure									
FeedBench									4
Payload Canister Exterior									6
Payload Canister Interior									5
Overall Totals:	7	0	0	0	7	7	7	16	83
Total RDHU Interfaces:	7	0	0	0	7	7	7	8	39

*** Contained Within RDHU or in other interface to RDHU**

**** Measured by DEU, Data sent to RDHU via serial stream**

Command and Telemetry List
(2 of 3)

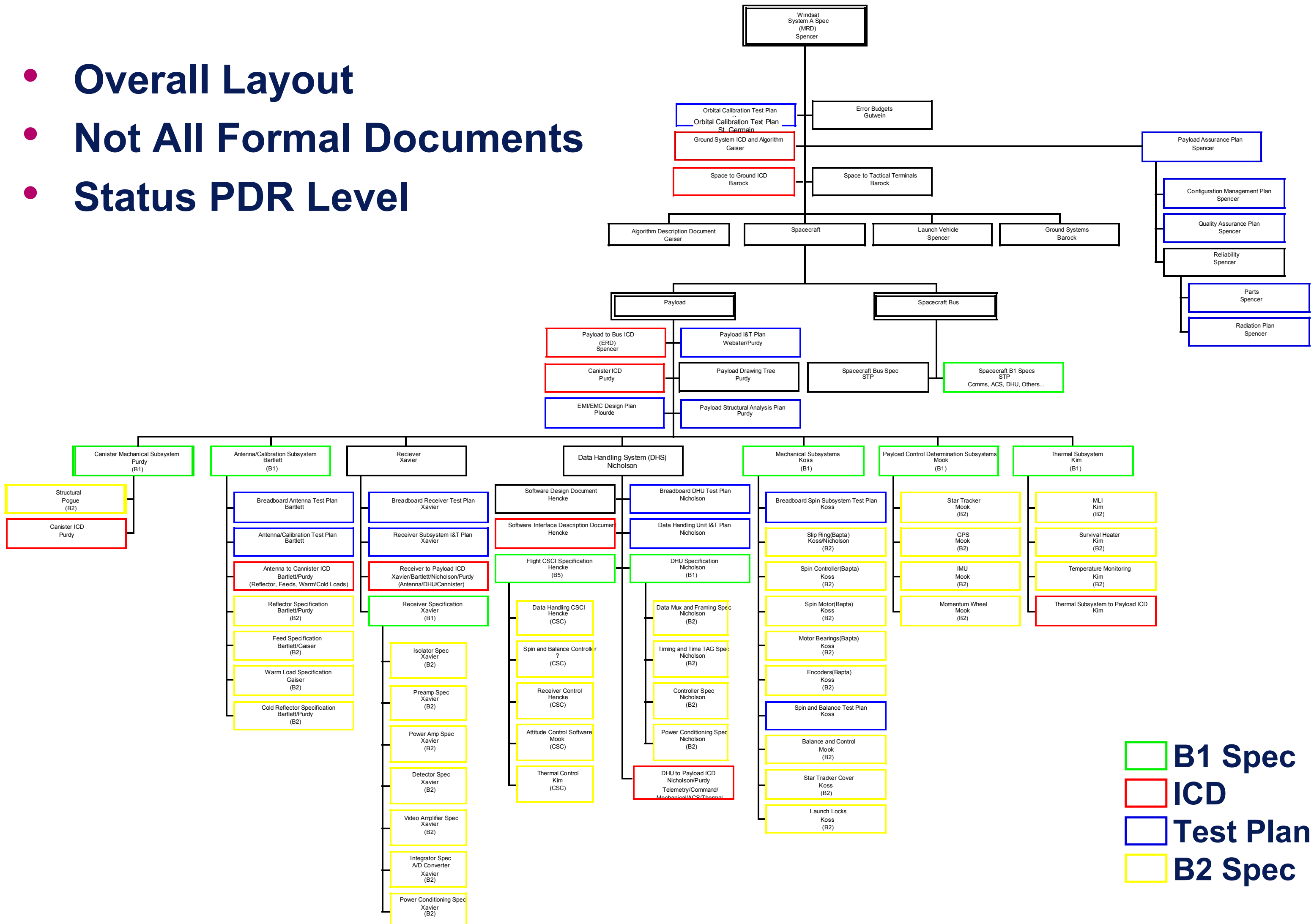
Stationary Side	Commands					Telemetry			
	Discrete		Digital			Digital		Analog	
Component	Pwr Relay Count	Other Relay Count	Bi-Level Count	Pulsed Count	Serial Count	Bi-Level Count	Serial Count	Voltages Count	Temp Count
PCD Subsystem									
Balance Sensors								12	
Star Tracker 1	1					1 *			1
Star Tracker 2	1					1 *			1
IMU	1					1 *		4	1
Momentum Wheel	4		1			6		6	2
Data Handling Subsystem									
Stationary DHU (SDHU)								4 *	1
Antenna/Calibration Subsystem									
Warm Load	1								
Cold Load									1
Canister Subsystem Structure									
Non-Rotating Canister									
Despun Deck Heat Pipes									4
BAPTA Control Electronics	2				2	2 *	2	5	2
BAPTA									1
Launch Locks	6					6			
Launch Lock Inhibit		6							
Bus RPI Switches									
Totals:	**16**	**6**	**1**	**0**	**2**	**17**	**2**	**31**	**14**

Command and Telemetry List
(3 of 3)

Bus	Commands					Telemetry			
	Discrete		Digital			Digital		Analog	
Component	Pwr Relay Count	Other Relay Count	Bi-Level Count	Pulsed Count	Serial Count	Bi-Level Count	Serial Count	Voltages Count	Temp Count
Top Deck Via Slip Ring									1
Feed Bench Via Slip Ring									1
Despun Deck									1
Survival Heater On/Off	1								
Survival Heater Current Monitor								1	
Payload on/off	1					1			
	2	0	0	0	0	1	0	1	3

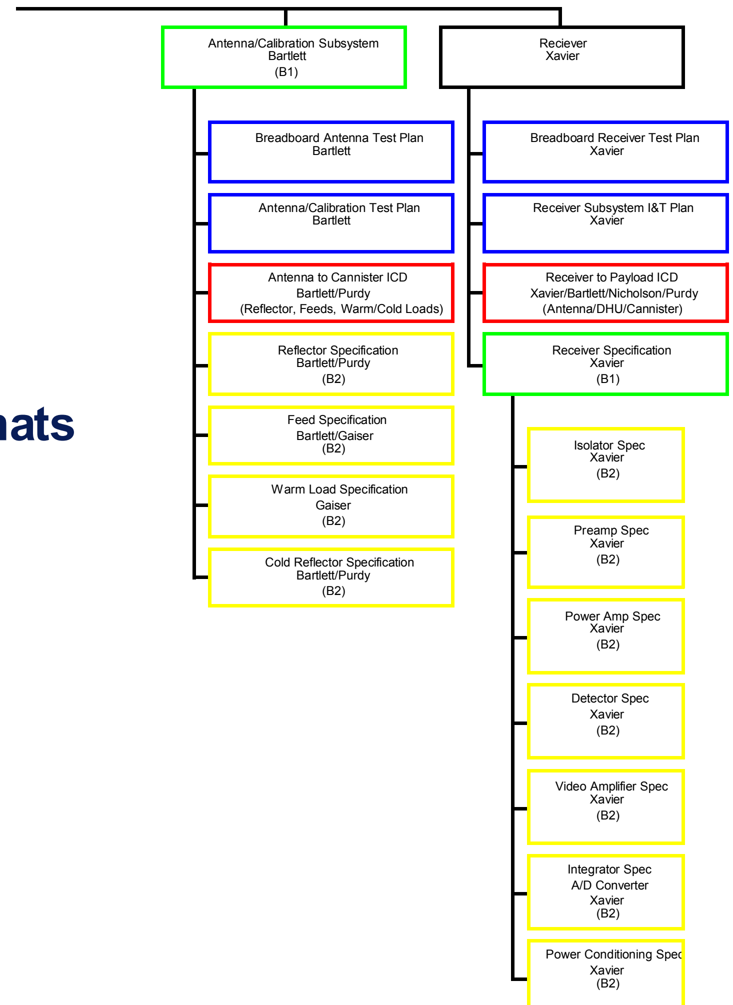
Document Tree and Documentation Status

- Overall Layout
- Not All Formal Documents
- Status PDR Level

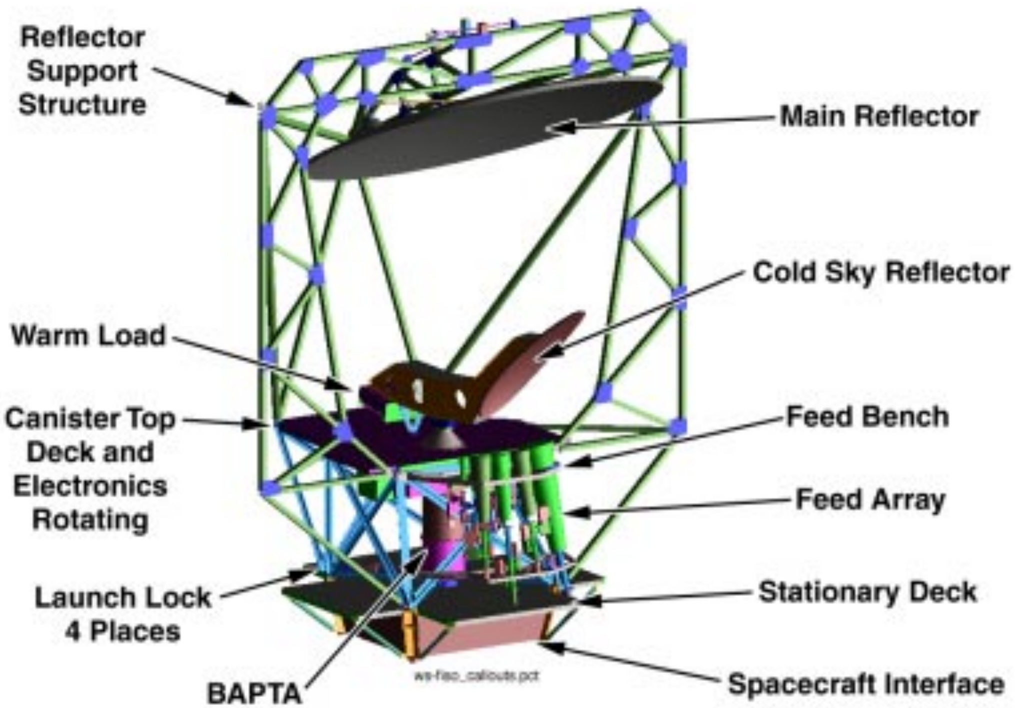


Sample Documentation

- B1 and B2 Level Structure
- Key Systems Shown
- Plans For All Tests
- All Informal/Engineering Note Formats
- Process Intent
- Interface Driven For PDR
- Key Derived Requirements
- Validations At System Level



Summary Analysis



- Beam Efficiency Asymmetry
- RFI
- Crosspol Sensitivity Analysis/Range Errors
- Rx Calibration Accuracy
- Range Geometry/Dynamic Range
- Reflector Surface Modeling
- Pointing Accuracy
- Rx A/D Head/Foot Room
- Feed Strut Modeling
- Feed Flush Resolution
- Data Link Analysis
- Dynamic Spin Balance
- Channel Thermal Balance
- Warm Load Heating/Uniformity

Payload Environments

Dave Spencer

Topics

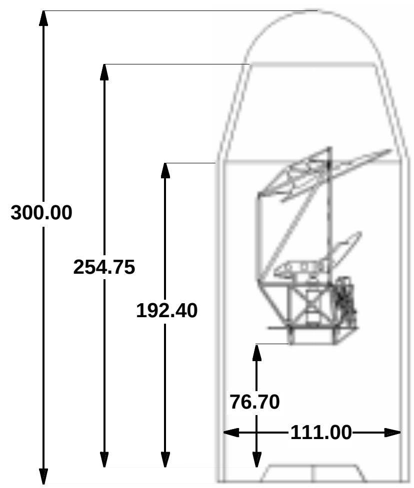
- Spacecraft Status
- Launch Vehicle Envelopes
- Launch Vehicle Environments
- Payload Shock Environment
- EMI/EMC Specifications
- Radiation Design Levels
- Temperature Ranges

Spacecraft Status

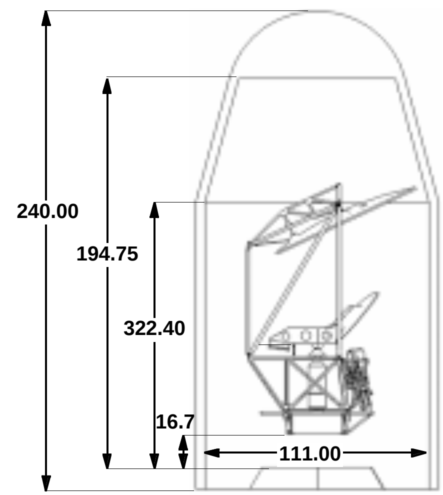
- Develop an Experiment Requirements Document (ERD) With the Space Test Program That Envelopes Spacecraft Interface Requirements to Allow for Payload Development
- A Study Will Be Performed by the Space Test Program (SMC/TEL), NRL and NASA Goddard's Integrated Mission Design Center (IMDC) to Determine Candidate Spacecraft Contractors From the NASA Rapid Spacecraft Development (RSD) Catalog
- Projected Spacecraft Authority to Proceed Is Required Prior to Payload CDR (12/98)

Launch Vehicle Envelopes

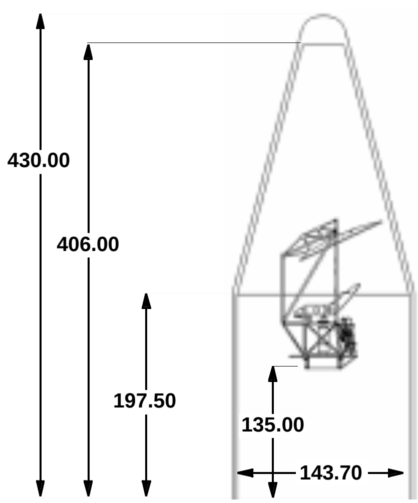
Titan- II 25 Foot Fairing



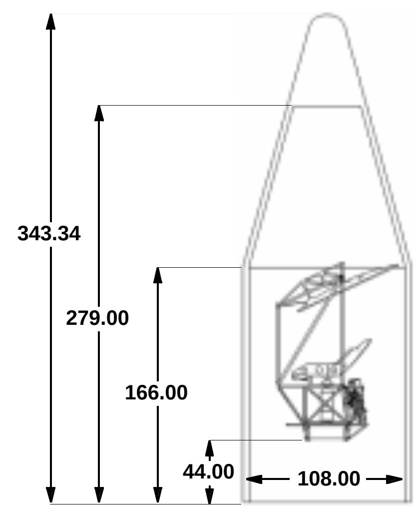
Titan- II 20 Foot Fairing



EELV/MLV



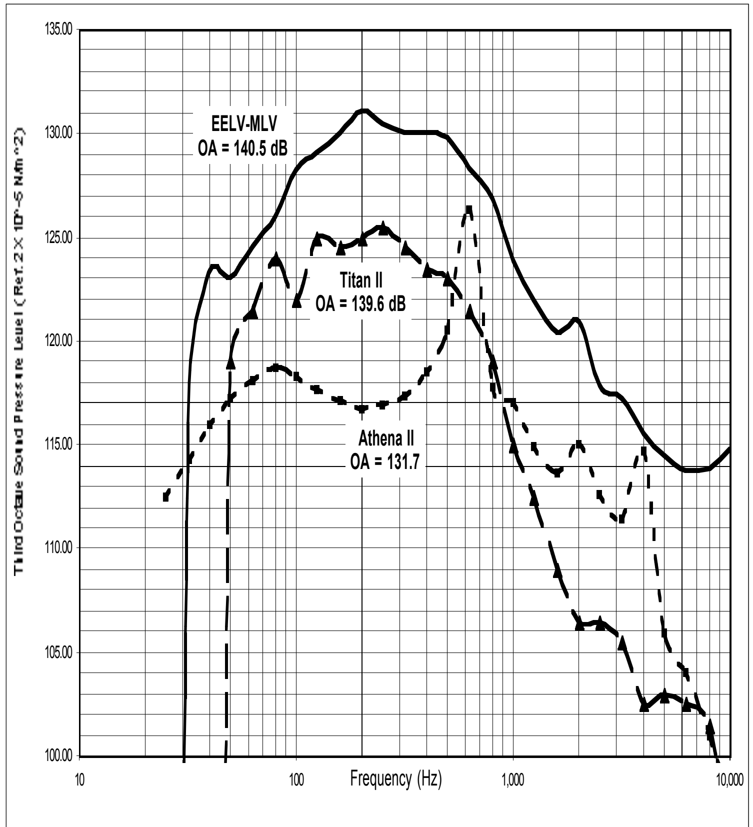
Athena 2



Launch Vehicle Acoustic Environment Comparison

- **EELV / MLV Acoustic Environment Envelopes Titan II and Athena2**

- **Acoustic Environment Is the Driver for Component Random Vibration Environments**

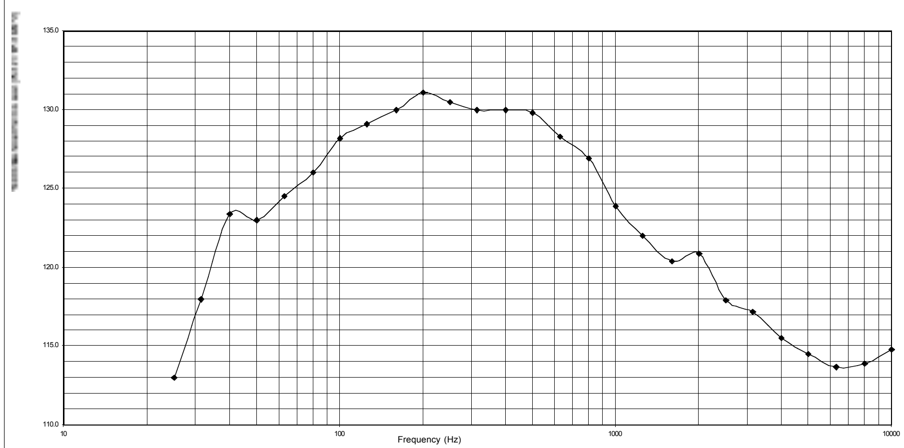


WindSat Flight Acoustic Environment
Comparison of EELV, Titan II & LMLV2

Flight System Level Acoustic Environment
Launch Vehicle Envelope - Acceptance Test Level

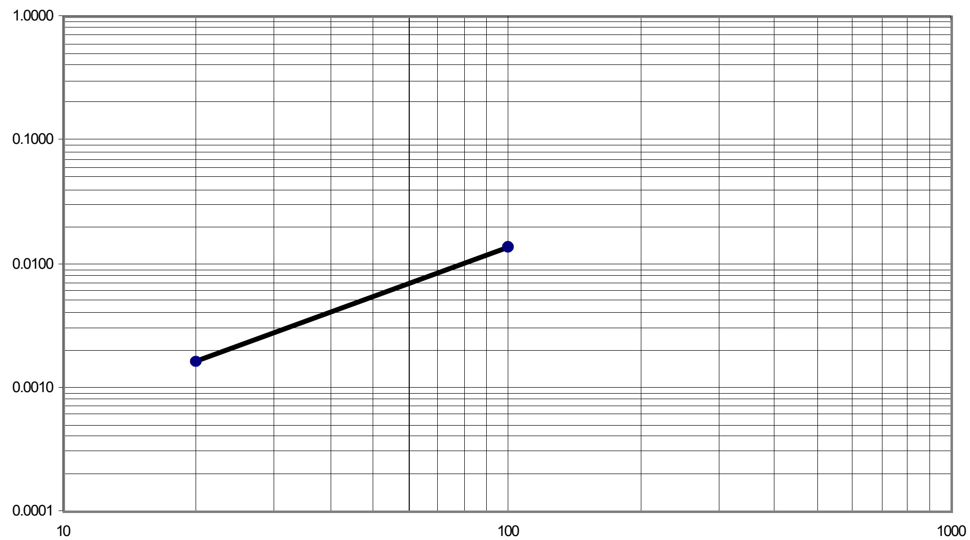
Flight Environment

One Third Octave Frequency (Hz)	SPL (dB)	One Third Octave Frequency (Hz)	SPL (dB)
25	113.0	800	126.9
32	118.0	1000	123.9
40	123.4	1250	122.0
50	123.0	1600	120.4
63	124.5	2000	120.9
80	126.0	2500	117.9
100	128.2	3150	117.2
125	129.1	4000	115.5
160	130.0	5000	114.5
200	131.1	6300	113.7
250	130.5	8000	113.9
315	130.0	10000	114.8
400	130.0		
500	129.8	OA	140.4
630	128.3		



WindSat Flight Acoustic Environment
Envelope of Titan II, EELV-MLV & LMLV2 Levels

Flight Random Vibration Environment
System Level Test - All Axes



WindSat System Flight Level Random Vibration Environment

Flight Environment

0.8 Grms

Frequency (Hz)	G^2/Hz
20	0.0016
100	0.0135

All 3 Axes

Test Level

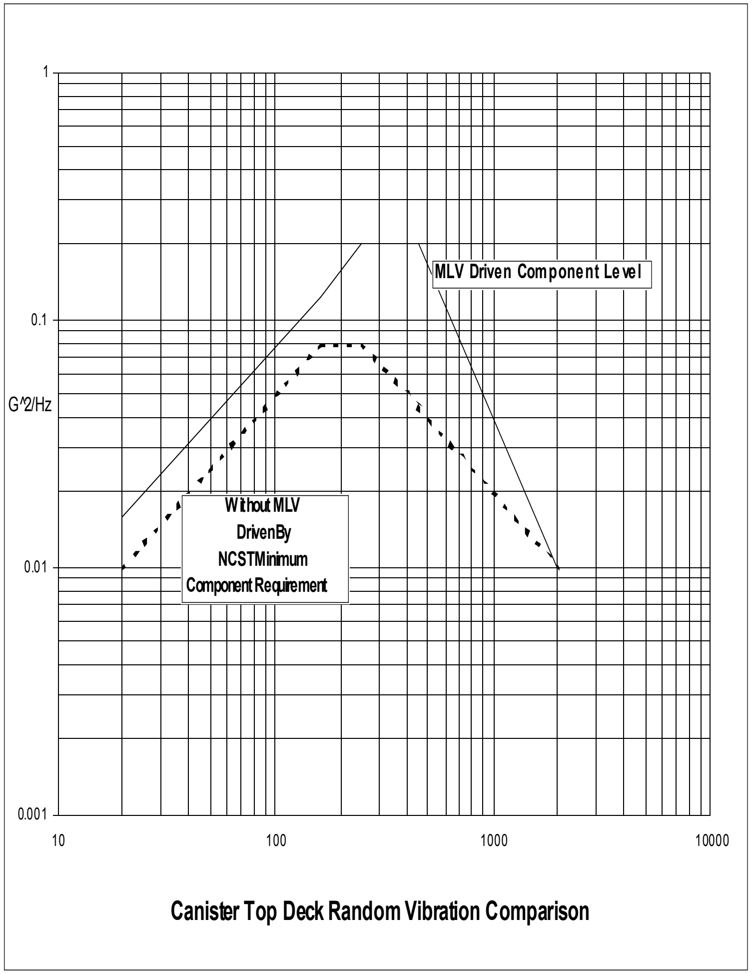
	Margin Above Flight Level (dB)	Duration (Minutes)
Engineering Model (Qualification Level)	6	2
Flight Spacecraft (Protoflight Acceptance)	3	2

Note: The Spectrum will be tailored to keep primary structural responses below DLL X 1.25 (EM) or DLL (Flight Spacecraft).

Effect of Launch Vehicle Acoustics on Canister Top Deck Random Vibration Environment

- **Higher EELV - MLV Acoustic Level Drive Component Random Vibration Test Level Higher**

- **Without EELV - MLV, in Envelope, Random Vibration Levels Decrease to NCST's Minimum Acceptance Environment in Most Cases**



Component Mass Acceleration Curve Design Loads - All Components

- **Curve Provides Estimate of Design Acceleration Loads**
- **These Loads, Multiplied By the Appropriate Factor of Safety, Are To Be Used for Design and Loads Testing**

Design Accelerations

Component Wt. (Lbs)	G's
0.1	60
1	60
100	20

Apply in 3 Axes - One axis at a time

Design Acceleration Philosophy

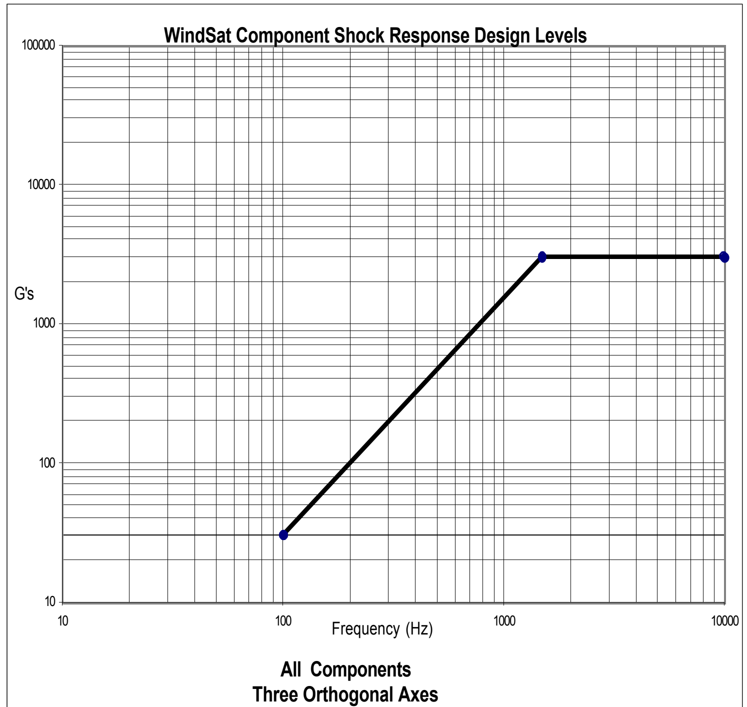
* These accelerations are to be used for design of components and their attachment

- For Designated Components, the acceleration level from this curve may also be used for random vibration test spectrum tailoring.

Component Pyroshock Environment
All Components

- **Preliminary Pyroshock Design Levels, Not for Component Level Testing**

- **Levels Will Be Refined As Design, Host Spacecraft and Launch Vehicles Evolve**



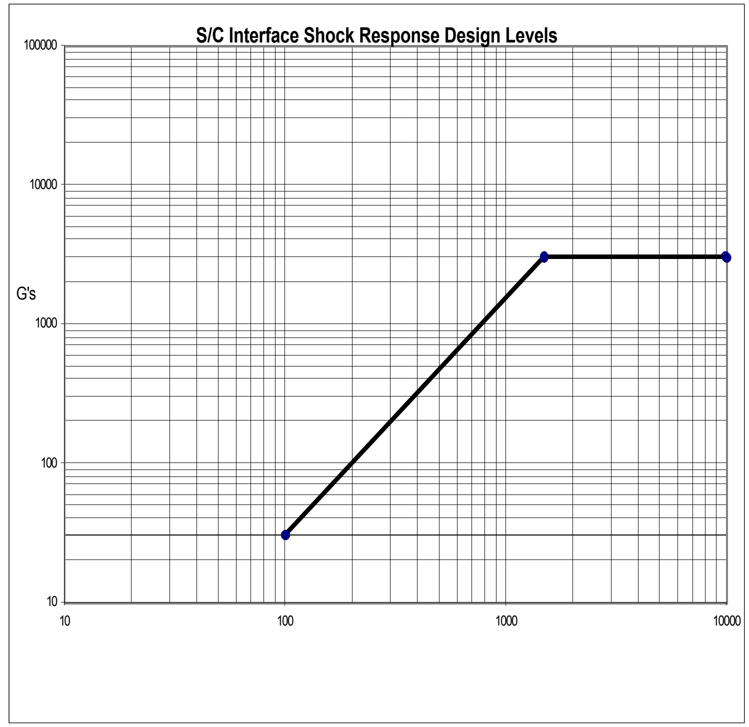
Shock Design Environment

Shock Response Spectrum Levels (Q = 10)

Frequency (Hz)	G's
100	30
1500	3000
10000	3000

S/C Interface Pyroshock Environment

- **Pyroshock Spacecraft Interface From Launch Lock Release**



Shock Design Environment

Shock Response Spectrum Levels (Q = 10)

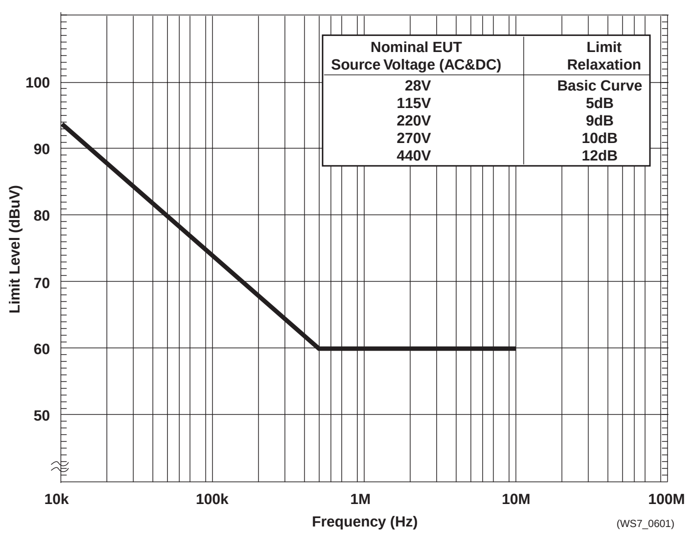
Frequency (Hz)	G's
100	30
1500	3000
10000	3000

Radiation Design Levels

- **Total Dose: 20 kRads**
  - Trapped Electron: 13.4 kRads
  - Proton Trapped 6.54 Solar Event 7.98 kRads Trapped Proton: 6.54 avg.
  - Assumes 82 Mils Spherical Aluminum Shielding Minimum
  - 3 Year Mission Safety Factor of 2
- **SEE / SEU / Latch-Up**
  - Threshold Levels: Rad-Hard > 80 MeV-cm2-mg
Rad-Tolerant: 20-80 MeV-cm2-mg
Req. Approval: <20 MeV-cm2-mg
  - Margin: All Functions Will Be Latch-Up Immune or Protected

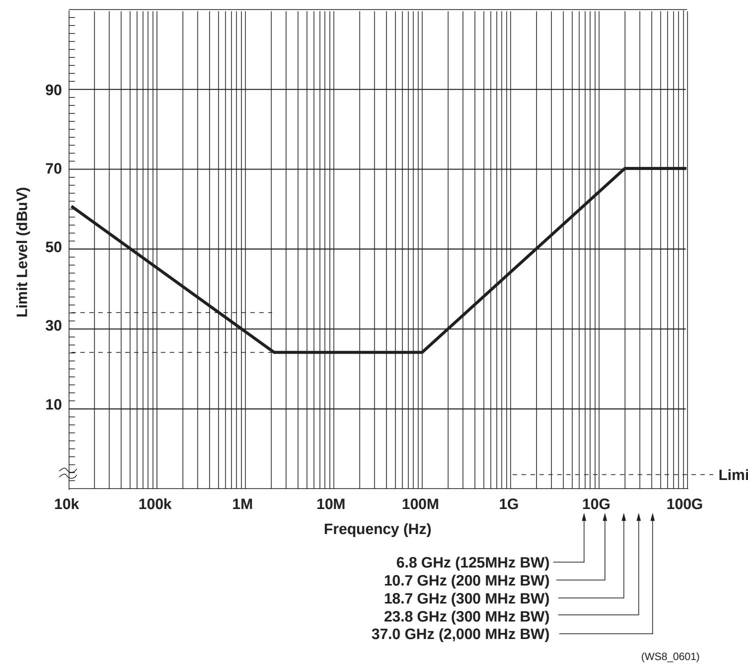
Power Line Conducted Susceptibility Damped Sinusoid

CE102 Limit (EUT Power Leads AC And DC) For All Applications

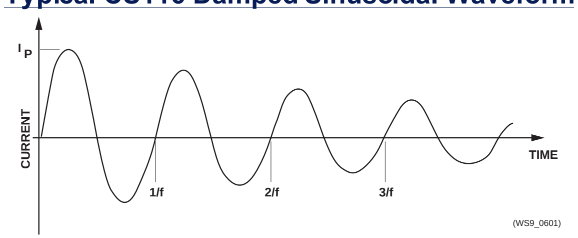


Limit Will Be Tailored Below 1 MHz Due To Filter Size/Weight Constraints

Radiated Emissions (RE102 Limits)



Typical CS116 Damped Sinusoidal Waveform



Notes: 1. Normalized Waveform $e^{-(\Pi f t)/Q} \sin(2\Pi f t)$
Where:
f = Test Frequency (Hz)
t = Time (sec)
Q = Damping Factor, 15 ±5

2. Damping Factor (Q) Shall Be determined As Follows:

$$Q = \frac{\Pi (N-1)}{Ln(Ip/In)}$$

Where:
Q = Damping Factor
N = Cycle Number (I.e. N=2, 3, 4, 5 . . .)
Ip = Peak Current At 1st Cycle
In = Peak Current At Nth Cycle
Ln = Latural Log

Maximum Allowable RF To Radiometer Coupling Level

Center Frequency (GHz)	6.8	10.7	18.7	23.8	37
Bandwidth (MHz)	125	200	500	500	2000
Maximum Coupling Level (dBm)	-127.7	-125.5	-120.7	-120.6	-113.4

- **Table Shows Maximum Levels Referenced At Feed Outputs Prior To LNAs**
- **Basis: Receiver Coupling Shall Be 35 dB Below Predicted System Noise Level Of Radiometer Channels At Same Reference Location**

EMI Test Matrix

Test \ Equipment	Data Handling Unit-Rotating	Data Handling Unit-Stationary	BAPTA	MWA Power Conditioner	Spin And Balance Electronics	Receivers	GPS Receiver	WINDSAT Payload	Total Payload and Spacecraft system With Downlink Transmitter
CE102, 10kHz To 10 MHz (NB)	N	N	N	Y	Y	Y	Y	Y	Y
Single Event Switching Transients	N	N	N	Y	Y	Y	N	N	Y
CE106, 10 KHz To 40 GHz	N	N	N	N	N	Y	Y	N	Y
CS101,, 30 Hz To 50 KHz	N	N	N	N	Y	Y	Y	N	Y
CS103, 15 KHz To 10 GHz	N	N	N	N	N	Y	Y	N	N
CS104, 30 Hz To 20 GHz	N	N	N	N	N	Y	Y	N	N
CS114, 10 KHz To 10 GHz	N	N	N	N	Y	Y	Y	N	Y
CS115, Bulk Cable Injection	N	N	N	N	Y	Y	Y	N	Y
CS116, 10 KHz To 100 MHz	N	N	N	N	Y	Y	Y	N	Y
RE102, 10 KHz To 18 GHz	Y	Y	Y	Y	Y	Y	Y	Y	Y
RS103, 10kHz To 10 GHz	Y	Y	Y	Y	Y	Y	Y	Y	Y
Radiated Susceptibility - ESD	Y	Y	Y	Y	Y	Y	Y	N	Y
RF Coupling Into Radiometer*	N	N	N	N	N	N	N	Y	N

* Can Be Combined With RS103

Electronics Box Baseplate Temperature Ranges

- Performance Temperature Range: 0 - 40C
  - Must Meet Error Budget Allocations
- Functional/Survival Range: -20°C to +60°C
- Note: These Ranges Pertain Only to Feed Bench, Canister, and Stationary Side Components
- Thermal Subsystem Must Meet All Requirements With 11C Margin

Mission Assurance

R. Mann

Mission Assurance Elements

- Configuration Management
- Design Analyses
- Parts and Components Sparing
- Parts Procurement and Processing
- Fabrication and Assembly
- Integration and Test
- Quality Control

Configuration Management (1 of 2)

- WindSat Configuration Management Plan (NCST-D-WS004)
- NCST Unique CM System
  - Drawings Plus All Control Documents Released
  - All In Release Record Computer Data Files
- Major Elements
  - Engineering Release Notice (ERN)
  - Configuration Change Notice (CCN)
  - Configuration Status Report (CSR); STAT-WS-001
  - Engineering Configuration List (ECL); ECL-WS-001
  - Accountability and Verification = As Built Configuration List (ABCL); ABCL-WS-001

Configuration Management (2 of 2)

- Change Control Board
  - Engineering Board
  - Senior Board

- Phasing and Milestones
  - Change Control of Documents
  - Change Control of Drawings
  - CSR
  - ECL
  - ABCL

Reliability Program

- WindSat Reliability and Mission Success Plan (NCTS-D-WS005)
- Design Analyses
  - Failure Modes and Effect Analysis (Top Level)
  - Structural Loads and Mechanical Stress Analyses
  - Electrical Stress Analysis
  - Electrical Worst Case Analysis
- Materials and Parts Control
  - Parts Selection and Specification to Level 3 Performance and Reliability Per 311-INST-001, Rev A
  - No Additional Screening at Part Level After Receiving Unless Specified in 311-INST-001
  - No Additional DPA at Part Level After Receiving
- Integration and Test
  - Box Level Test Cycle and Buy-off
  - Integrated Experiment Test Cycle and Buy-off

Parts Plan

- Selection
  - MIL-STD-975, Grade 2 Parts List, When Applicable
  - MIL-STD-883 Class B Microcircuits
  - JANTXV,JANTX Semiconductor Devices
  - Passive Devices Procured Under Established Reliability Level of RSS and RRS
  - Semi-Custom Parts (e.g., DC/DC Conv.) Procured at the Class B Equivalent Level
  - Existing NRL Flight Stock of Screened Parts
  - Parts Able to Withstand Total Dose Level of 20 krads (NCST-D-WS006)
- Qualification to Level 3 Per 311-INST-001, Rev A
  - No Additional Screening Upon Delivery of Parts Unless Noted in 311-INST-001
  - No DPA Is Planned on Received Parts
- Acquisition
  - Purchase From Known Vendors With Good History
  - Require Certificate of Compliance
  - Consult With Parts Engineer When Needed
- Application
  - Parts Will Be Derated According to NCST Requirements in SSD-D-210

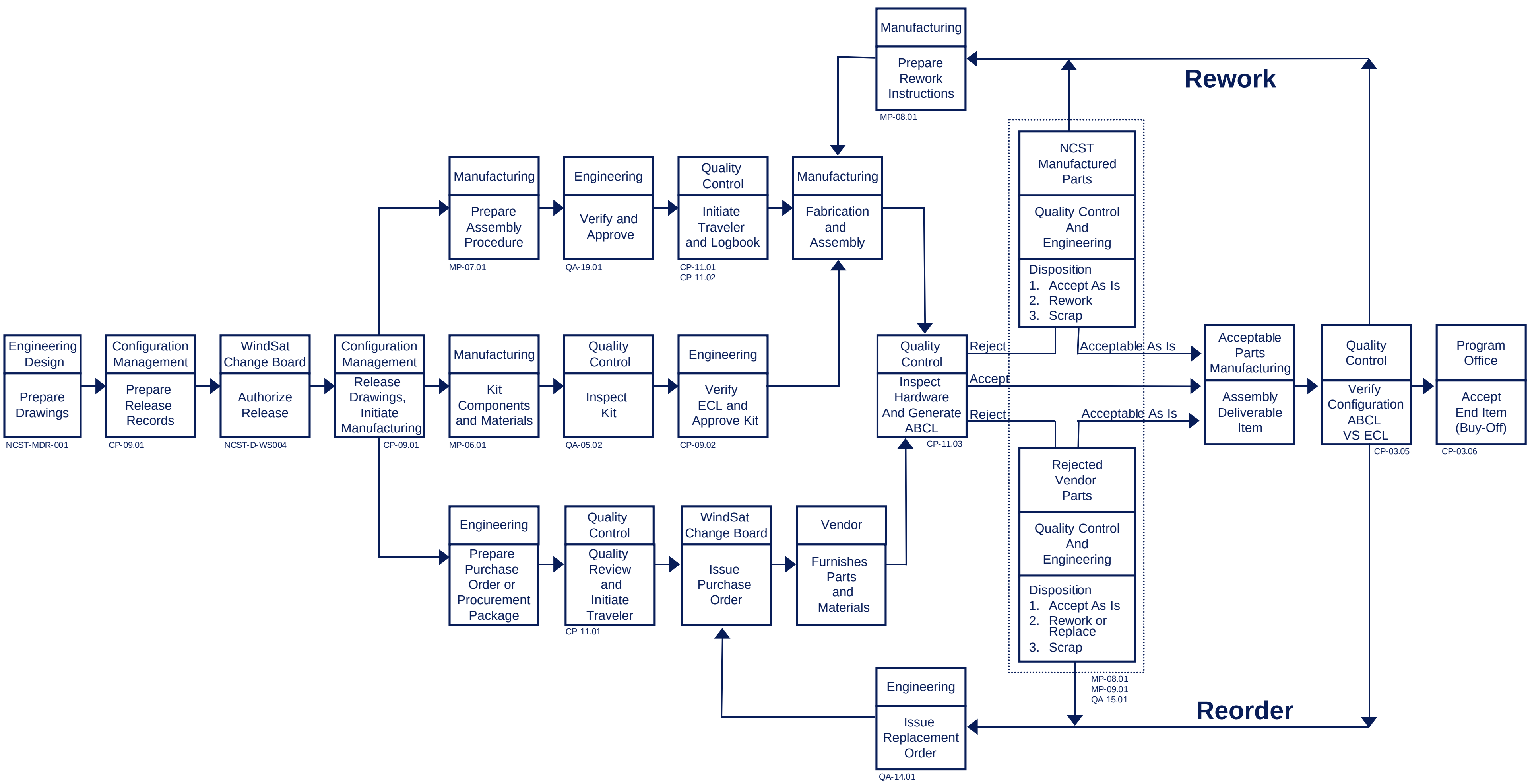
Sparing Plan

- Low Cost EEE Parts and Mechanical Materials Spares Based on Previous Experience
- EEE Parts Build to Buy Quantity Factors Based on Figure 4-1 of SSD-D-002 Using Program Spares (No Additional DPA)
- Program Manager Review and Approval if Individual EEE Part Cost Exceeds Defined Amount
- Sparing of High Cost Purchased Components Based on Review of (1) Lead Time, (2) Reliability and Life Expectancy, and (3) Unit Cost

Quality Control

- Elements of NCST Quality Assurance Program Implemented Through the WindSat Quality Assurance Plan (NCST-D-WS003)
- Implemented With Control Procedures in NCST-MCP-001; Manufacturing Procedures (NCST-MMP-001); and Quality Assurance Procedures (NCST-MQA-00)
- Elements Include Design Control, Procurement Control, Fabrication Control, Inspection and Test, NMR and Failure Control and the Development of Quality Records

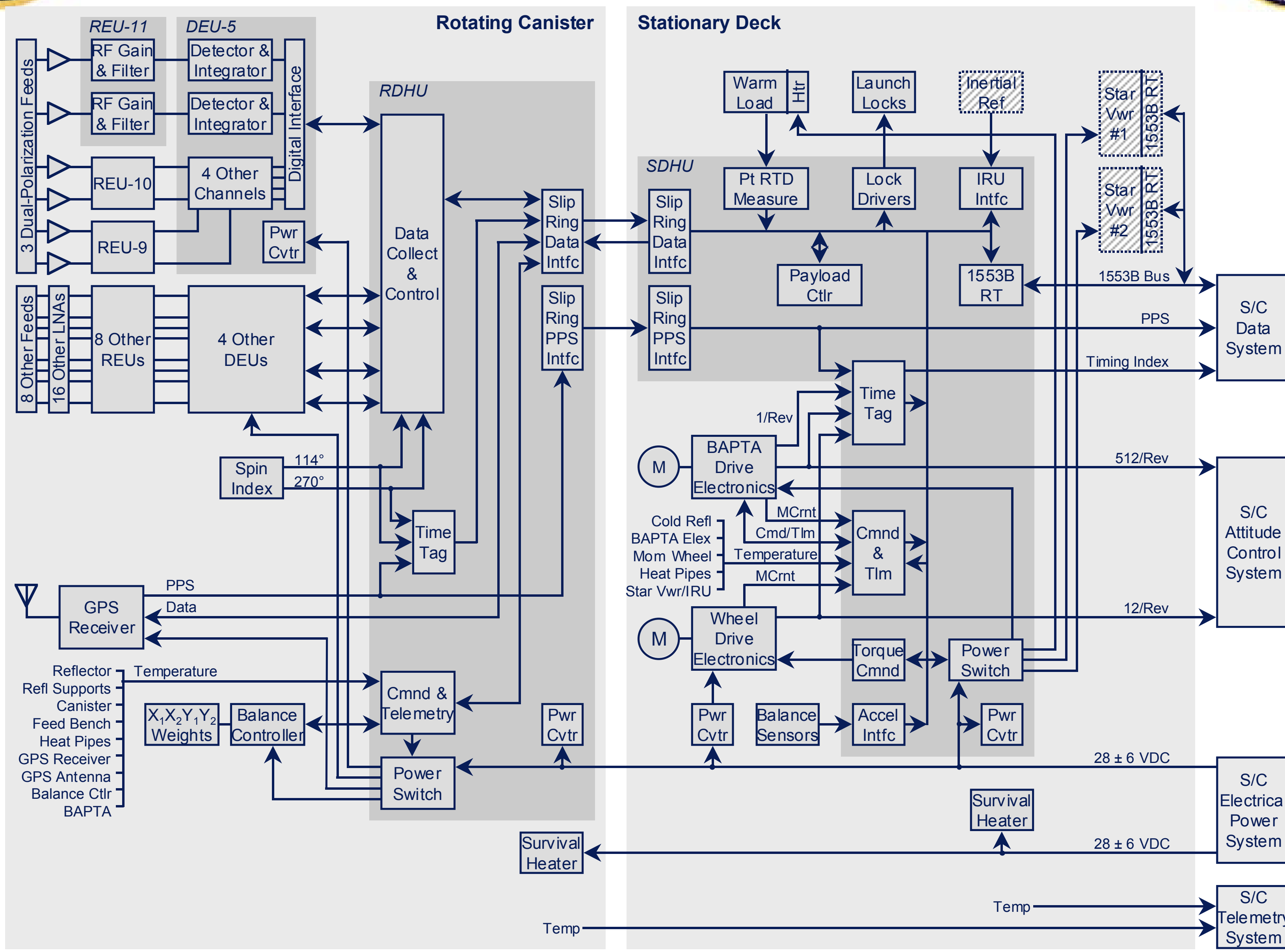
Quality Program Flow



WindSat Payload Electronics

Bill Webster

WindSat Electrical Block Diagram



Payload Electronics Agenda

- Antenna Subsystem
- Payload Receiver
- Power Conditioning
- Data Handling
- Software
- GPS Receiver
- EAGE

WindSat Payload Power Estimates

Spun Side Sensor Payload Subsystems		
Item	Total Power No Margin	Total Power With Margin
Rcvr/Det. Subsystem Include. Horns	157.7 W	220.7 W
Data Handling Subsystem	24.6 W	34.4 W
Sensor Canister Structure / Misc	5.0 W	7.0 W
Thermal Control Subsystem	0.0 W	0.0 W
Spun Side Total	187.3 W	262.2 W

Despun Side Sensor Payload Subsystems		
Item	Total Power No Margin	Total Power With Margin
Data Handling Subsystem	57.1 W	80.0 W
Calibration Subsystem	5.0 W	7.0 W
Pointing Control Subsystem	50.0 W	70.0 W
Structure/Misc	6.9 W	9.7 W
Thermal Control Subsystem	0.0 W	0.0 W
Despun Side Totals	119.0 W	166.6 W

Payload Totals	
Power No Margin	Power With Margin
306.3 W	428.8 W

Power Growth Margin = 40%

Antenna Subsystem

Wendy Lippincott
Homer Bartlett

Outline

- Summary of Changes Since SRR
- Antenna Derived Requirements/ Compliance Summary
- Antenna Baseline Design
- Antenna Mechanical Design
- Antenna Analysis/ Predicted Performance
- Antenna Range Overview
- Antenna Breadboard Test Results

Changes Since SRR

- Feed Horn Design Complete (CORHORN Program Used)
- 10.7 GHz Feedhorn Built and Tested
- Preliminary Range Data Obtained and Analyzed
- Horn Tolerance Analysis Complete
- Range Sensitivity Analysis Complete
- Struts Analysis Complete
- Reflector Surface Distortion Analysis Complete

Windsat Antenna Derived Requirements

Specification	Requirement	Design Compliance (by analysis)
Diameter	72 inches	Yes
Focal Length	61.6 inches	Yes
VSWR	1.25	Yes
Boresight Alignment	< 0.015 deg.	Yes
Rotational Alignment of horns	< 0.018 deg.	Yes
Phase Center Stability	+/- 0.1 λ (axially and laterally)	Yes
Positional Tolerance of horns	< 17 mil	Yes
Reflector Manufacturing Tolerance	< 4 mil	Yes
Reflector Thermal-Induced Roughness On-Orbit	< 3 mil	Yes
Reflector Effective Roughness	< 5 mil (rss of 4 and 3 mil)	Yes

Derived Requirements: Antenna Frequency Dependent Requirements

Freq. GHz	Bandwidth MHz	Stokes Parameter Calibration* dB	Beamwidth deg.	Design Compliance (By Analysis)
37	2000	30	0.34	Yes
23.8	500	23	0.53	Yes
18.7	500	30	0.68	Yes
10.7	200	30	1.2	Yes
6.8	125	23	1.9	Yes

- **Feed Performance Must Be Consistent With Knowledge of Stokes Coupling Terms to These Accuracies**

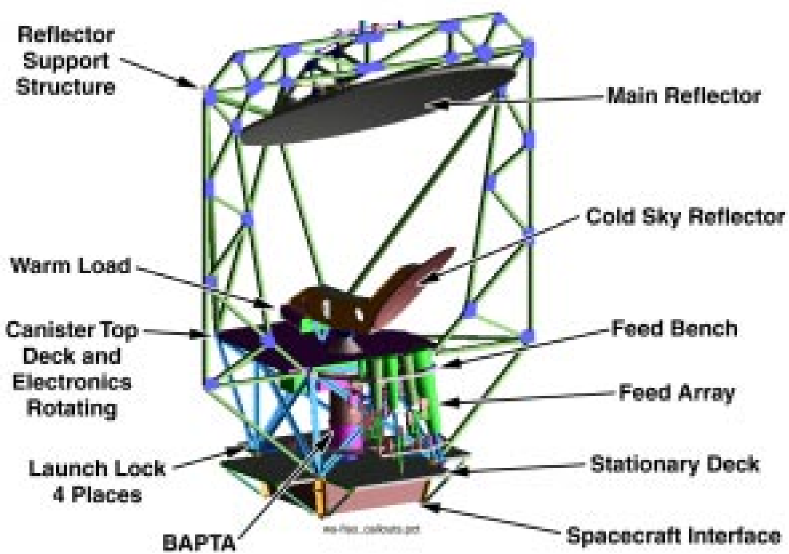
Windsat Antenna Derived Requirements: Insertion Loss

Subsystem	6.8	10.7	18.7	23.8	37
Antenna					
Horn Loss	0.02	0.03	0.06	0.07	0.11
OMT Loss	0.02	0.03	0.06	0.08	0.12
Transmission Loss	0.12	0.03	0.05	0.06	0.09
Isolation	0.01	0.01	0.01	0.01	0.01
VSWR Mismatch	0.05	0.05	0.05	0.05	0.05
Subtotal Antenna Pre LNA Loss	0.22	0.15	0.23	0.27	0.38
Allocated Loss	0.30	0.30	0.30	0.30	0.40
Margin (dB)	0.08	0.15	0.07	0.03	0.02

Derived Requirements for Feed Losses to Support Allocated NEDT for Antenna Subsystem

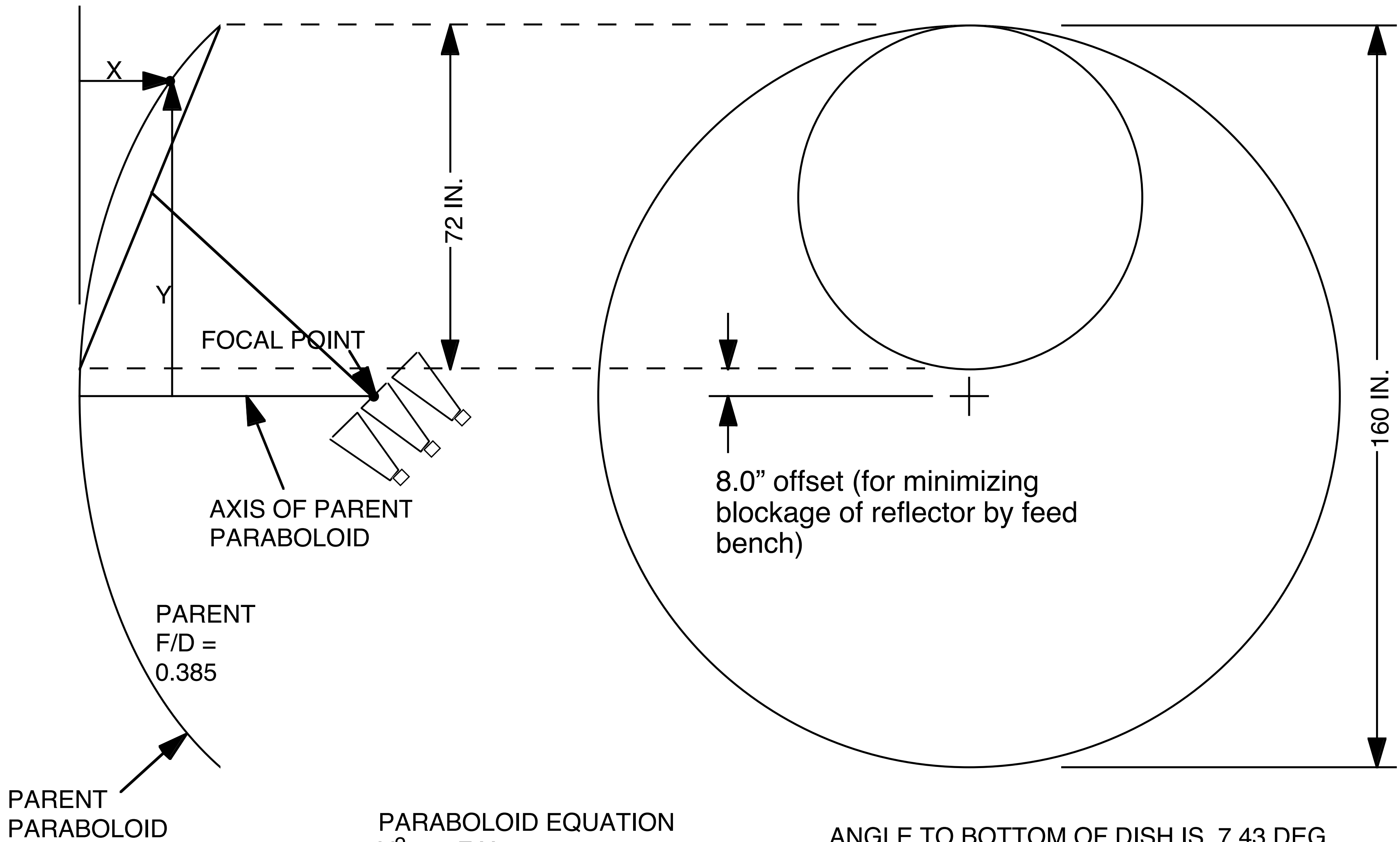
Design Compliant with Insertion Loss Requirements by Analysis

Antenna Baseline Design Overview



- Composite 6 Foot Main Reflector
- Low CTE Composite Truss
- 11 Horn Feed Array
- High Polarization Isolation Feeds
- Rotation Rate 30 Rpm

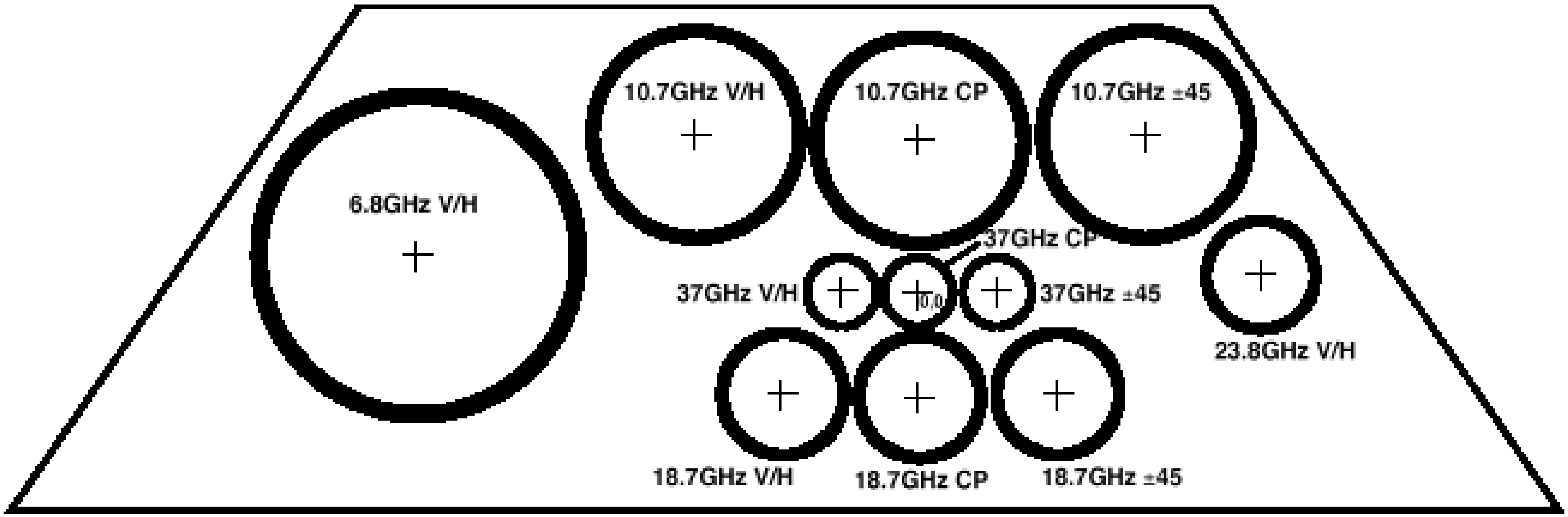
Antenna Baseline Design: Offset Parabolic Reflector



PARABOLOID EQUATION
$Y^2 = 4 F X$
F (FOCAL LENGTH) = 61.6 IN.

ANGLE TO BOTTOM OF DISH IS 7.43 DEG
ANGLE TO TOP OF DISH IS 66.0 DEG

Antenna Baseline Design: Conical Corrugated Feedhorn Array

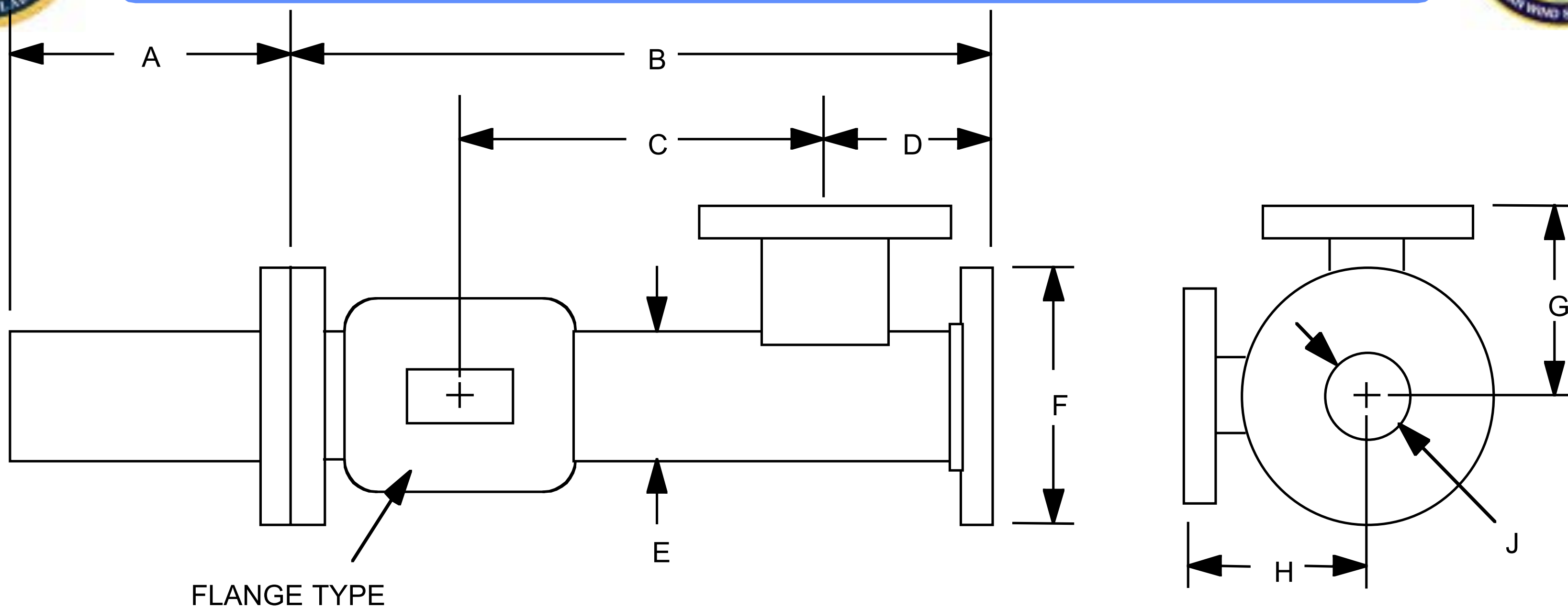


- **Polarimetric Horn Placements (10.7, 18.7, and 37 GHz) on Feed Bench Optimized for Best Stokes Coupling Parameters.**
- **37 GHz Horn Placed Nearest to Focal Point to Minimize Offset in Wavelengths**
- **Non-polarametric Feeds (6.8 and 23.8 GHz) Are Kept at Same EIA (Earth Incidence Angle) As 37 GHz Feeds**

Antenna Baseline Design: Corrugated Conical Horns Dimensions

Frequency (GHz)	Inner Diameter (inches)	Outer (inches)	Flare Length (inches)
6.8	5.445	6.720	20.302
10.7	3.478	4.292	13.099
18.7	2.053	2.534	7.409
23.8	1.598	1.972	5.684
37	1.063	1.312	3.627

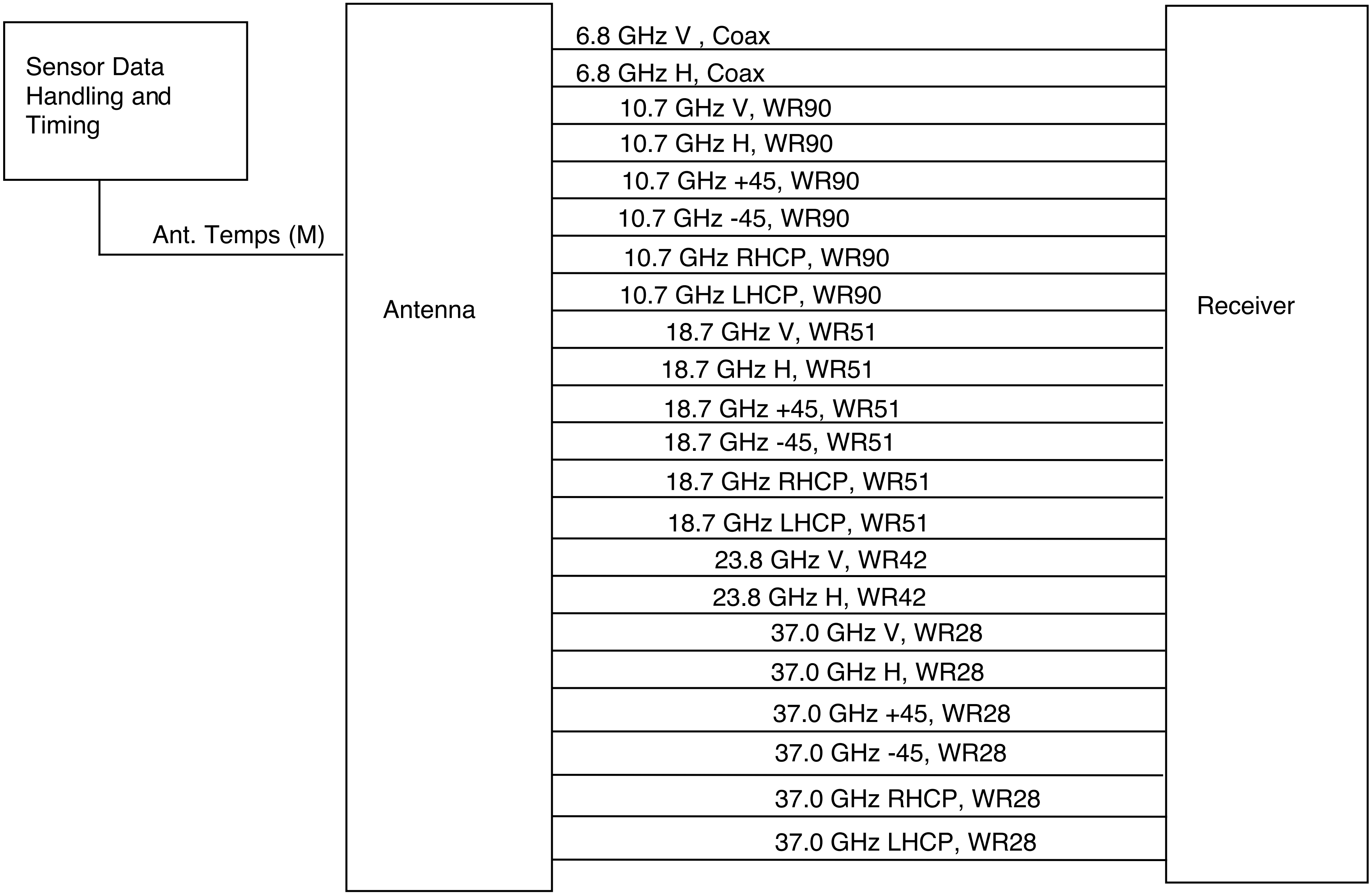
Orthomode Dimensions



FREQUENCY	A	B	C	D	E	F	G	H	J	FLANGE TYPE
37.0 GHz	1.125	3.875	1.250	1.750	0.375	0.950	0.750	0.750	0.250	WR28 COVER
23.8 GHz	1.750	4.000	1.700	1.500	0.500	1.250	1.000	1.000	0.375	WR42 COVER
18.7 GHz	2.250	4.500	2.000	1.500	0.750	1.750	1.250	1.250	0.450	WR51 COVER
10.7 GHz	3.000	6.200	3.000	1.550	1.000	2.500	1.400	1.400	0.750	WR90 COVER
6.8 GHz	1.000	8.200	3.000	2.500	1.500	3.125	2.000	2.000	1.250	WR137 COVER

10.7 GHz Orthomode breadboard meets all RF requirements
Orthomode size dictated by polarization isolation requirements
Orthomode design compliant with dimensional constraints

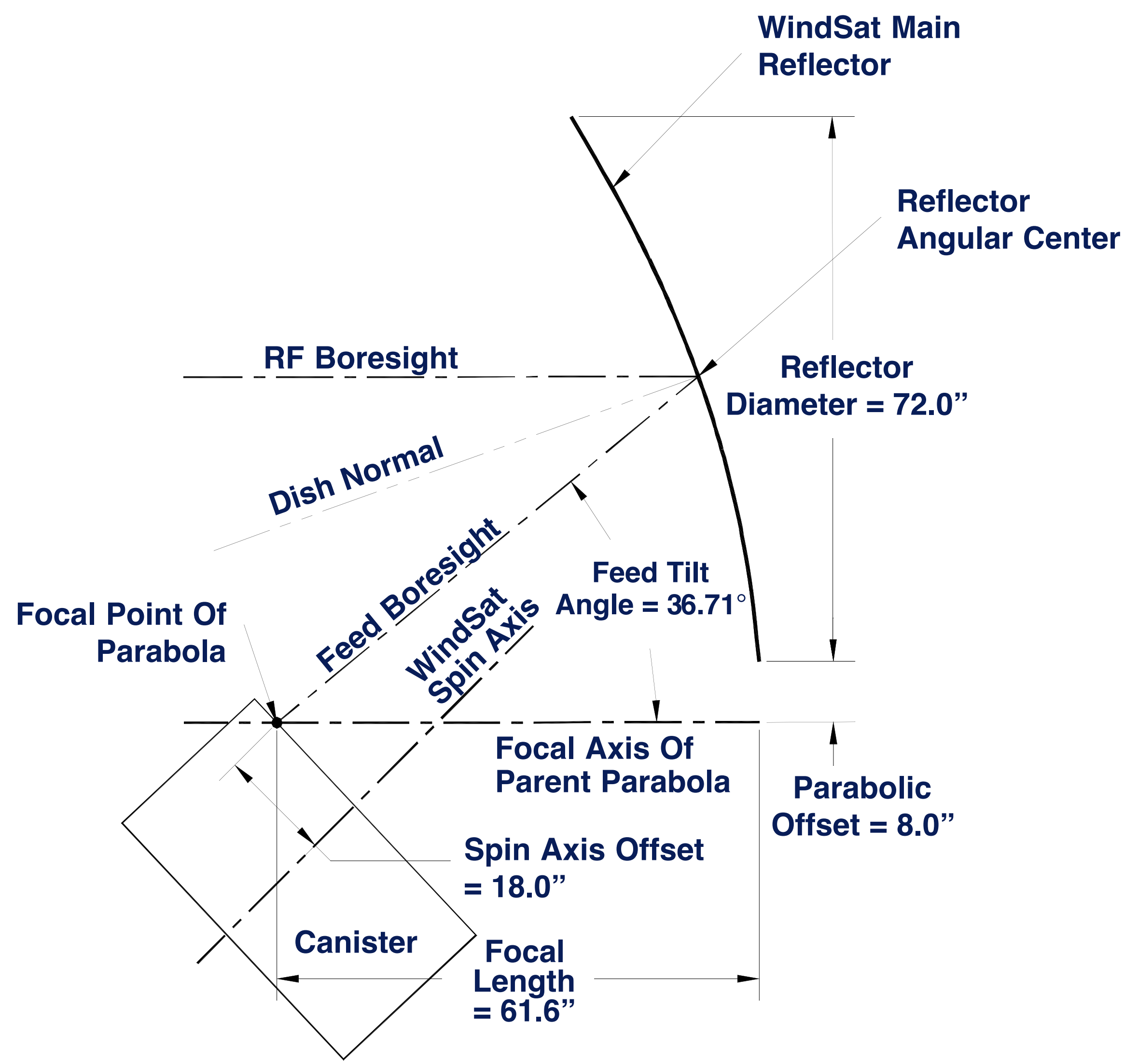
Antenna Baseline Design: Interface Design



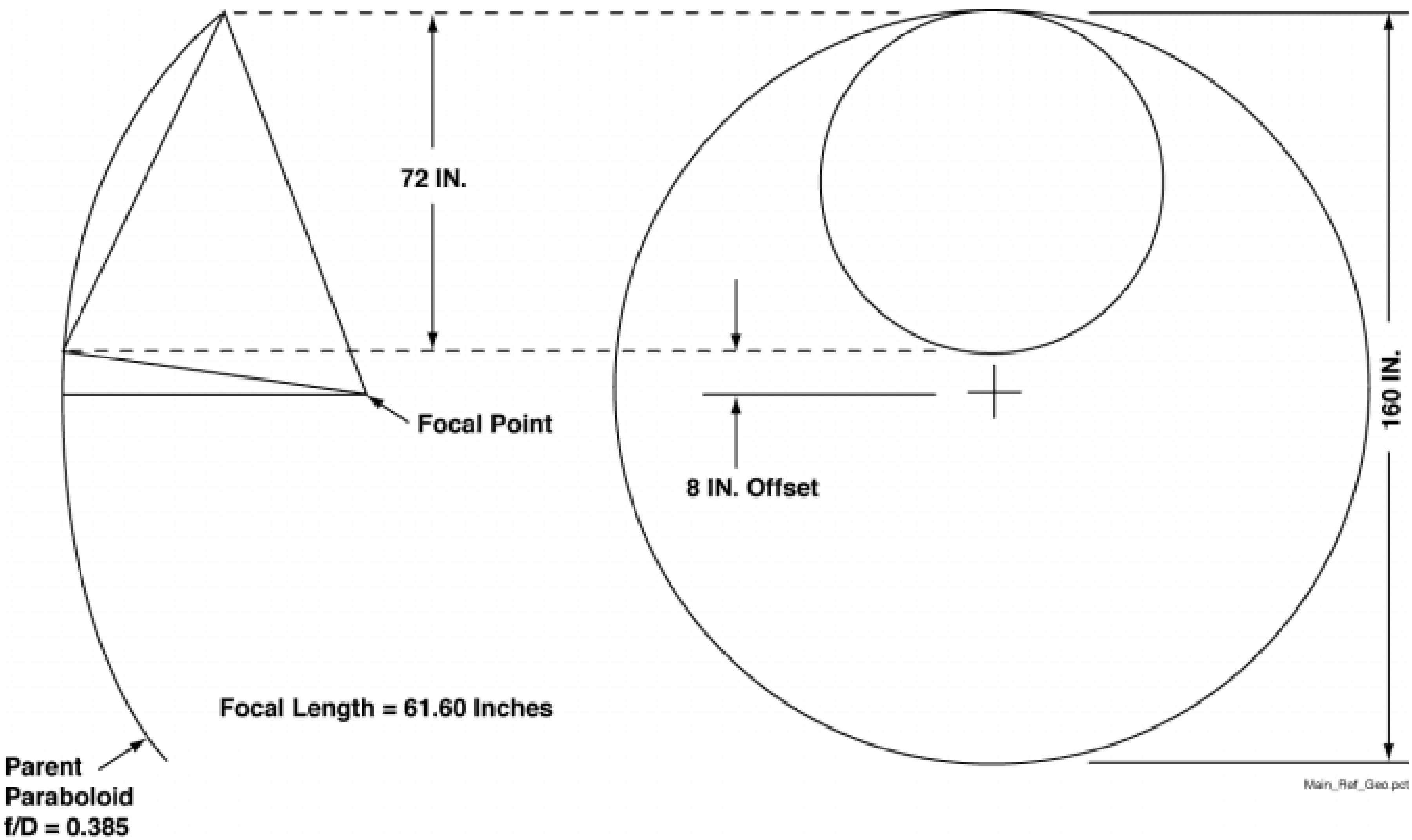
Antenna Reflector

W. Pogue

Antenna Nomenclature and Baseline Geometry



WindSat Main Reflector: Geometry



WindSat Main Reflector: Derived Requirements

- Manufacturing Tolerance: 4 mil rms
- Gravity Offload and Thermal-Induced Tolerance
  - On-Orbit: < 3 mil rms
- Effective Roughness (rss of 3 & 4 mil): < 5 mil rms
- Interface Hard Points on Rear
- Adjustable For Rotation About Dish Normal
- “Similar” To Cold Reflector
- Front Surface: Microwave Reflectivity > 0.9995 @ 37 GHz
- Minimize Weight: < 15 lb.

Main Reflector: Analysis

- Mechanical
  - First Mode min. 40 Hz
  - Mounting point Selection

- Thermal
  - Temp. Range : -4 to 110 °C
  - Gradient of : 45 °C Yields distortion of : < .002” RMS

- RF
  - Geometry / Structural Influence / Reflections
  - Beam Efficiency Analysis by Wendy Lippincott

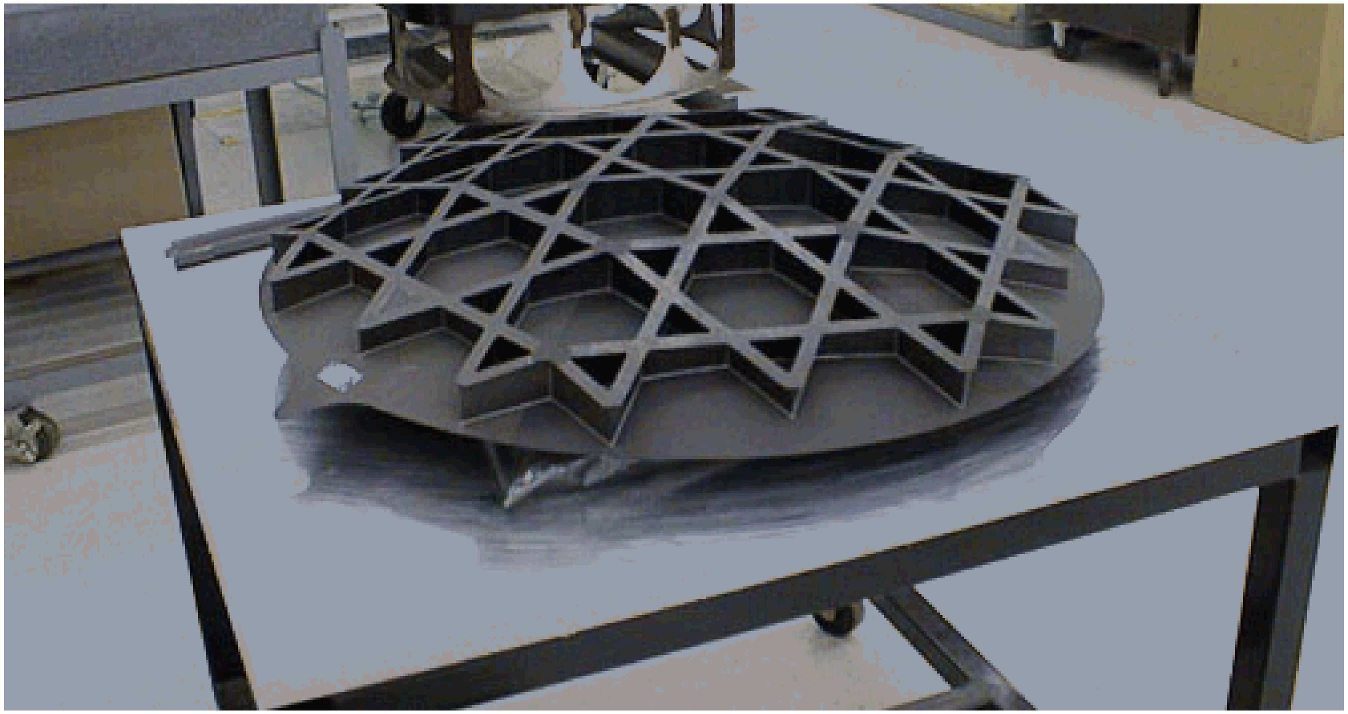
Main Reflector : Trades Made

- Material: Aluminum vs. Composite
  - Aluminum Unsatisfactory: Manufacturing Tolerance,
  - Aluminum Unsatisfactory: High CTE
  - Composite Wins: Meets Requirement, Heritage Good
- Structural Type: Sandwich vs. Single Skin
  - Single Skin more Expensive but Tighter Tolerance
  - Single Skin Requires Taller Reinforcing Ribs and Taller Support
  - Sandwich Structure: Heritage to < 5 mil RMS
  - Sandwich Wins: Meets Minimum Performance at Lower Cost with Shorter Support Structure Required

WindSat Main Reflector: Design Baseline

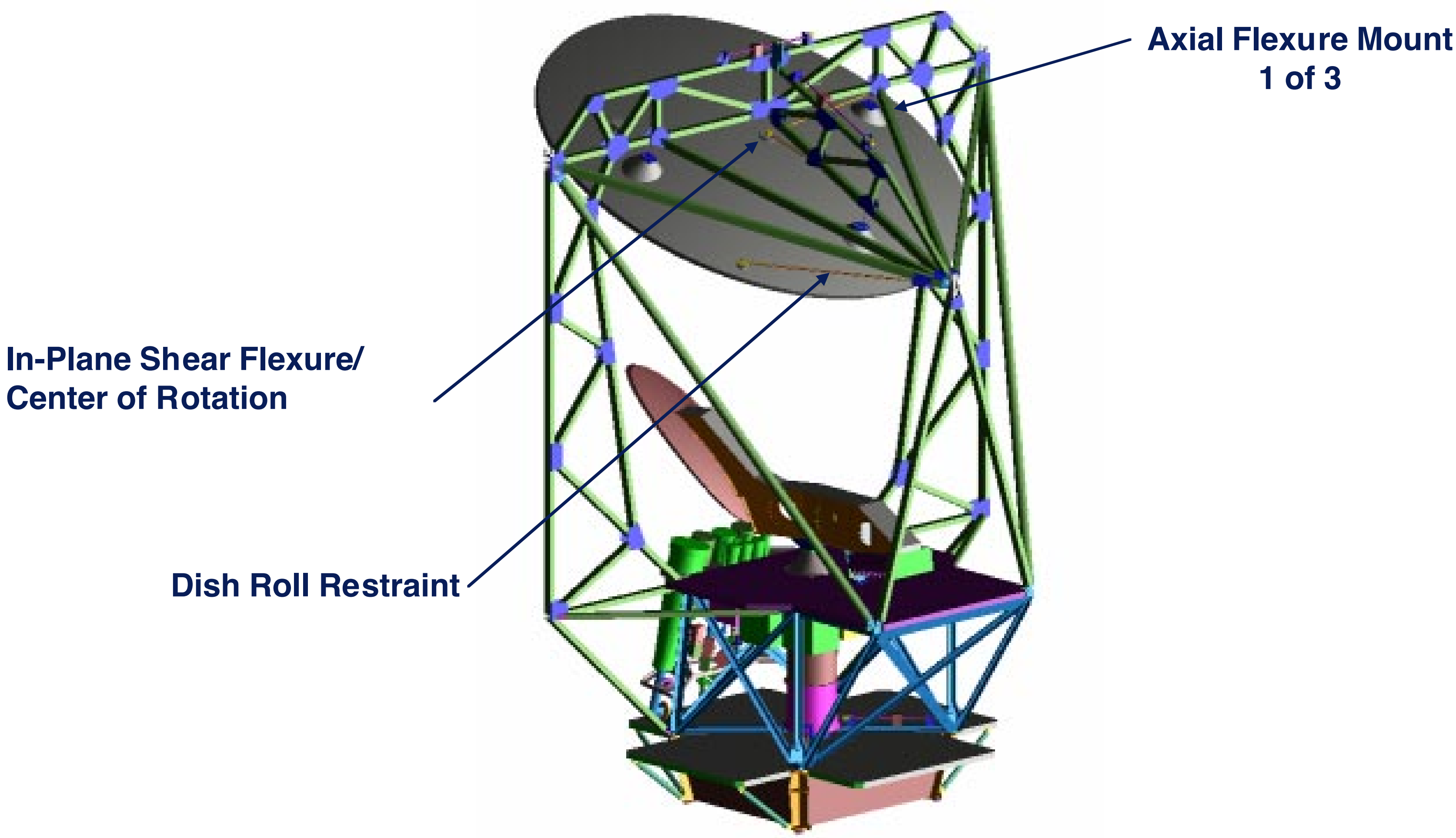
- Offset Paraboloid Geometry
- Thermally Stable Composite
- Sandwich Construction
  - Nomex Honeycomb Core
  - Graphite Cyanate Composite (M55J/954-3) Face Sheets
- Backing Structure
  - Graphite Cyanate Ribs
  - Adhesively Bonded
- Titanium Mounting Hard Points on Rear Surface
- Mounting Points for Optical Cubes
- Vapor Deposited Aluminum, Polished Front Surface
- Reflectivity > 0.9995 @ 37 GHz
- Cold Reflector Will Be of Similar Construction

Composite Reflector With Reinforcing Ribs

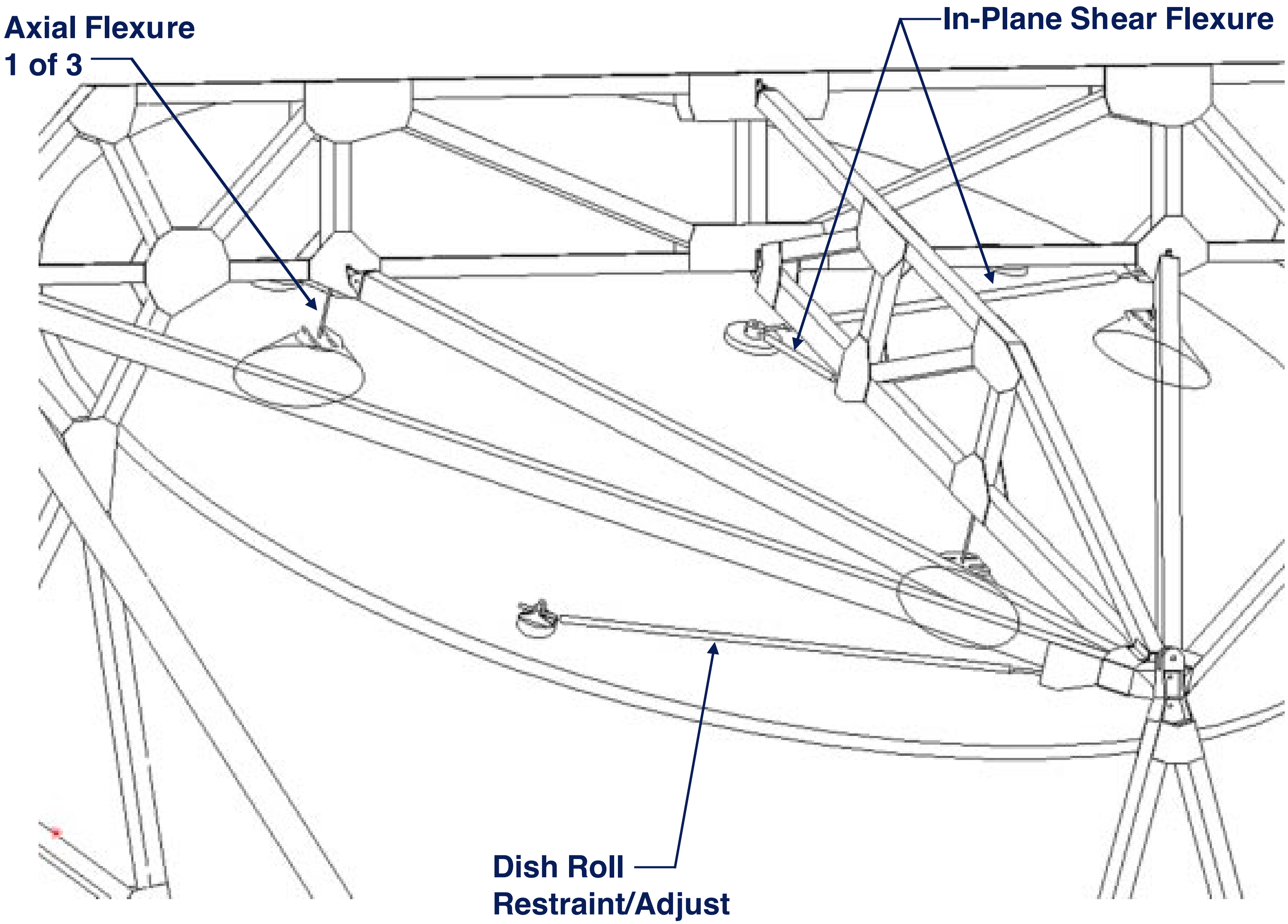


WindSat Main Reflector Interface

- **Semi-Kinematic Mount**



WindSat Main Reflector: Interface (Close-Up)



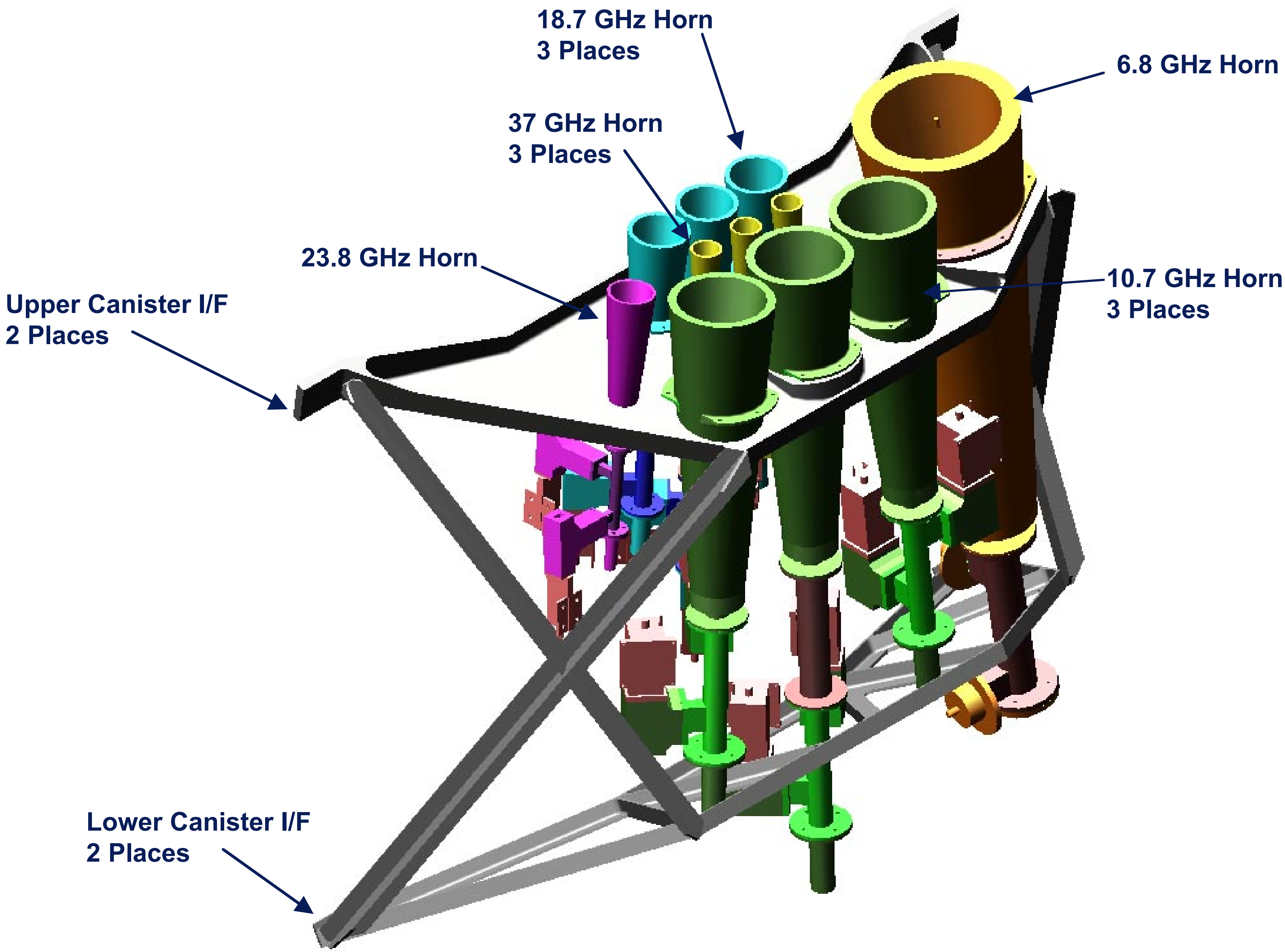
Main Reflector:
Implementation Plan, Flight Unit

- In- House Analysis
  - Mechanical
  - Thermal
  - RF
- Design
  - RF Driven Geometry / Surface Finish (Front)
  - Structure Driven Configuration of Interface (Rear)
- Competitive Buy to Specification
  - Multiple Vendors Identified With Heritage and Capability
  - Concurrent Design Effort With Vendor
- EBB versus Flight
  - Take Delivery of Tooling for Future Manufacturing or CMIS Technology Transfer
  - Investigating Use of Single Reflector For EBB and Flight Use

Antenna: Feed Bench

S. Cottle

Antenna: Feed Bench

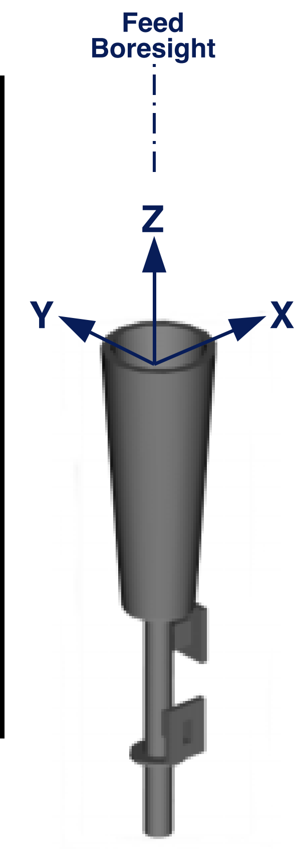


Requirements

Item	Requirement
Feed Bench	Provide Structural Interface Between Feedhorns and Payload Canister
Feedhorn Location	37 GHz CP Horn Phase Center Located at Main Reflector Focus
Feedhorn Location	All Feedhorns Positioned in Array Per Horn Location Chart (by Iteration With POE Code). Positions Referenced From 37 GHz CP Horn
Feedhorn Location	37 GHz CP Horn Phase Center Located 18” From Payload Spin Axis (Derived From Antenna Geometry Requirements)
Feedhorn Location	All Horn Faces Flush to Focal Sphere Swept From Main Reflector Angular Center
Feedhorn Pointing	Horns Pointed at Main Reflector Angular Center
Feedhorn Pointing	37 GHz CP Horn Tilt Angle of 36.71°
Feedhorn Adjustment	CP Horns Fixed to Feed Bench With No Adjustments. All Other Horns Adjustable Per Adjustment Chart
Feedhorn Support	Support Feedhorns to Survive Launch, Static Loads, Vibration & Acoustic Environments
Thermal	Provide Thermal Radiator Area for Thermal Control Of LNAs

Feedhorn Adjustment Requirements

		Rotation				Translation			
Feed Freq. (GHz)	Polarization	Rx*	Ry*	Rz Range	Rz Resolution	Dx Range	Dx Resolution	Dy	Dz
6.8	V/H	Fixed	Fixed	> ±0.5°	0.015°	Fixed	N/A	Fixed	Fixed
10.7	±45	Fixed	Fixed	> ±0.5°	0.015°	±0.10"	±0.005"	Fixed	Fixed
10.7	CP	Fixed	Fixed	Fixed	N/A	Fixed	N/A	Fixed	Fixed
10.7	V/H	Fixed	Fixed	> ±0.5°	0.015°	±0.10"	±0.005"	Fixed	Fixed
18.7	±45	Fixed	Fixed	> ±0.5°	0.015°	±0.10"	±0.005"	Fixed	Fixed
18.7	CP	Fixed	Fixed	Fixed	N/A	Fixed	N/A	Fixed	Fixed
18.7	V/H	Fixed	Fixed	> ±0.5°	0.015°	±0.10"	±0.005"	Fixed	Fixed
23.8	V/H	Fixed	Fixed	> ±0.5°	0.015°	Fixed	N/A	Fixed	Fixed
37.0	±45	Fixed	Fixed	> ±0.5°	0.015°	±0.10"	±0.005"	Fixed	Fixed
37.0	CP	Fixed	Fixed	Fixed	N/A	Fixed	N/A	Fixed	Fixed
37.0	V/H	Fixed	Fixed	> ±0.5°	0.015°	±0.10"	±0.005"	Fixed	Fixed



* Accuracy of ± 0.5°

Notes:
Feedhorn Coordinate System Centered on Feed Boresight Axis and Feed Phase Center
X Corresponds to Elevation
Y Corresponds to Azimuth
Z Corresponds to Focus
Focus Adjustment of Antenna Performed by Main Reflector
All Adjustments to Be Performed Based on RF Measurements Made at RF Range

Feedhorn Location Requirements

Feed Freq. (GHz)	Polarization	X Location	Y Location
6.8	V/H	0.704	9.959
10.7	±45	3.133	-4.492
10.7	CP	2.995	0.000
10.7	V/H	3.133	4.492
18.7	±45	-2.142	-2.711
18.7	CP	-2.192	0.000
18.7	V/H	-2.142	2.711
23.8	V/H	0.318	-6.723
37.0	±45	0.017	-2.249
37.0	CP	0.000	0.000
37.0	V/H	0.017	2.249

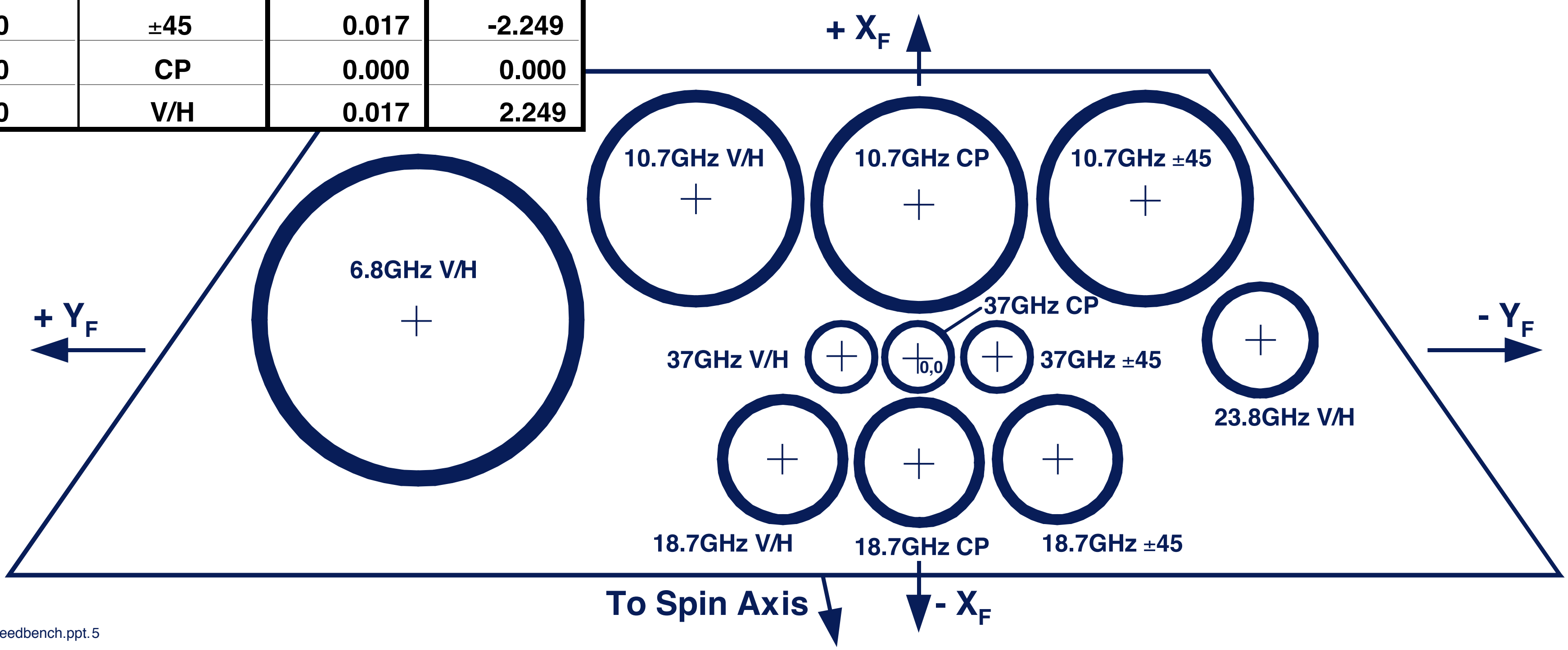
Notes:

Feed Bench View From Main Reflector

Feed Bench Coordinate Origin At 37 GHz CP Horn Phase Center

Minimum Horn Edge-To-Edge Spacing = 0.175”

Dimensional Tolerances ±0.017” Or Better



Changes From SRR

- Horn Positions Modified Slightly Due to Changes in Spin Axis Offset and Horn Position Optimization With POE Code
- Horn Location on Focal Sphere Modified to Minimize Adjacent Horn Shading
  - SRR: Horn Phase Centers Flush With Focal Sphere Swept From Main Reflector Angular Center
  - PDR: Horn Faces Flush With Focal Sphere
- Horn and OMT Sizes Increased Based on Antenna Trade Studies
- Eliminated Horn Focus Adjustment Requirement
  - Focus Adjustment Now Performed by Main Reflector
- Added X-Direction Adjustment Requirement For Offset Horns
  - Compensates For EIA Error (Due to Manufacturing Errors, Analysis Errors, etc.)
- Reduced Minimum Rotation Range Requirement for Polarized Horns
  - SRR: ±1°; PDR: ±0.5°
- Tightened Horn Rotation Adjustment Resolution Requirement
  - SRR: 0.05°; PDR: 0.015°

Completed Trades (1 of 3)

- Feed Bench Hard Mounted to Sensor Canister vs. Kinematic Mounts
  - Trade Driver Is Thermal Distortion Mismatch Between Canister And Feed Bench
  - Canister And Bench Both Aluminum; Temperature Difference Between Canister and Bench Very Small (<5°C)
  - Selection: Feed Bench to Be Hard Mounted to Canister
  - Removable Assembly With Repeatable Installation
- Feedhorn Mounting
  - Single Point vs. Two Point Mount
    - Two Point Mount Chosen (One on Horn, One on OMT) to Lower Single Point Loads Due to Cantilevered Assembly Mass
  - Semi-Compliant vs. Rigid Lower Point Mount
    - Laterally Rigid, Axially Compliant Mount Chosen to Constrain Lateral Motion and Allow Axial Thermal Expansion of Horn/OMT Assembly

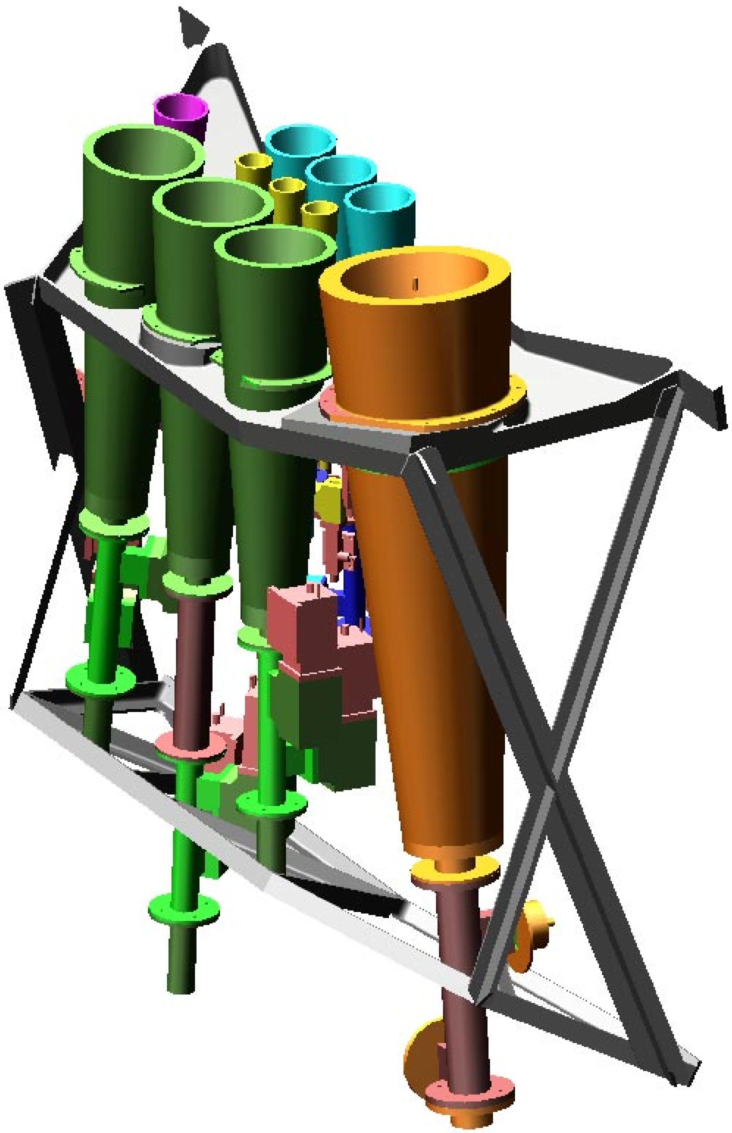
Completed Trades (2 of 3)

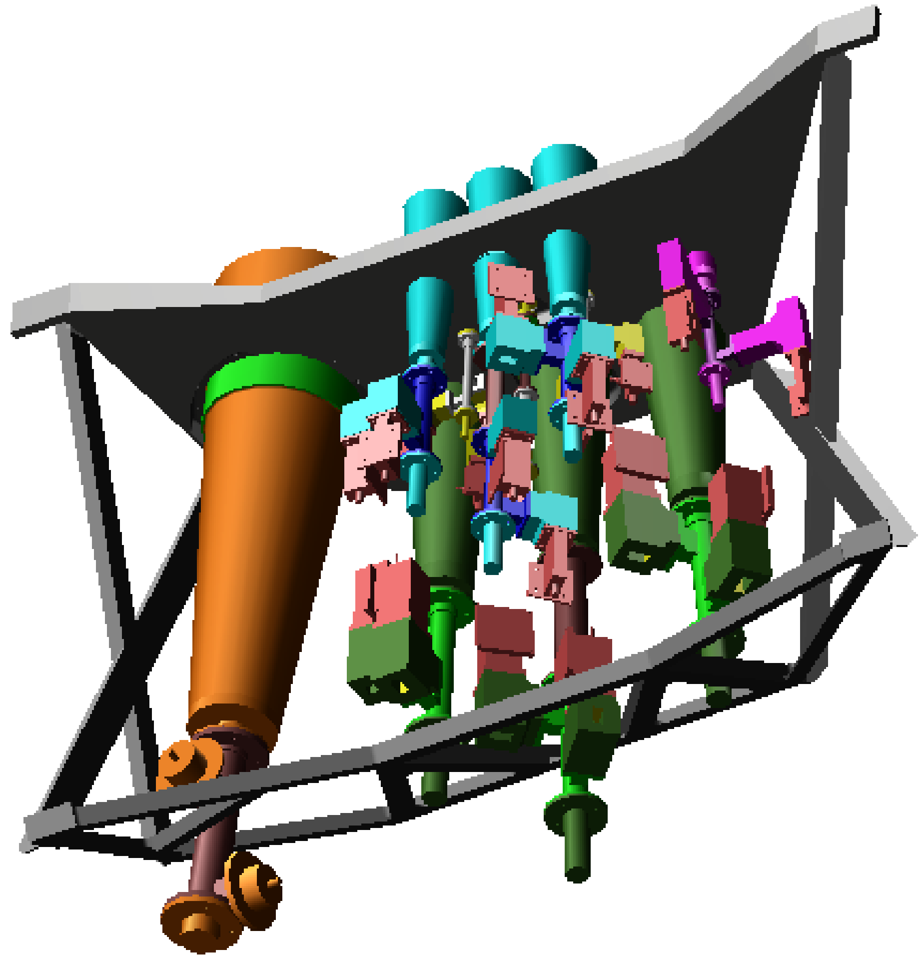
- Feedhorn Rotation Adjustment
  - Manual Rotation
    - Pros: Simplicity, Low Weight, Potential 360° Travel
    - Cons: Very Difficult to Provide Required Resolution
  - Micrometer Adjuster
    - Pros: Provides Required Resolution
    - Cons: Large Size, Weight, Limited Travel, Moderate Complexity
  - Worm And Gear
    - Pros: Provides Required Resolution, Potential 360° Travel
    - Cons: Size, Access, Weight, Complexity
  - Conical Screws
    - Pros: Provides Required Resolution, Small, Low Weight, Simplicity, Easy Top Down Access
    - Cons: Limited Travel, Friction Sensitive
- Conical Screw Method Chosen For Simplicity, Low Weight, Accessibility

Completed Trades (3 of 3)

- Feedhorn ±X (Elevation) Adjustment
  - Machined, Precision-Fit Horn Locating Seats
    - Pros: Simplicity, Low Weight
    - Cons: Must Remove Insert (Possibly Horn) From Feed Bench to Adjust. Must Machine Adjusted Location Feature. Not Real-Time Adjustment
  - Screw/Micrometer Linear Adjustable Seat
    - Pros: Very High Resolution, Real-Time Adjustment
    - Cons: Complexity, Access, Size, Higher Weight
  - Shim-Adjustable Seat
    - Pros: Provides Required Resolution, Simplicity, Low Weight
    - Cons: Crude Adjustment
- Choice: Combination Screw/Shim Adjustable Seat. Seat Located With Permanent Post-Measurement Shim Insert and Fixed With Locked Screw Adjuster

Feed Bench Assembly





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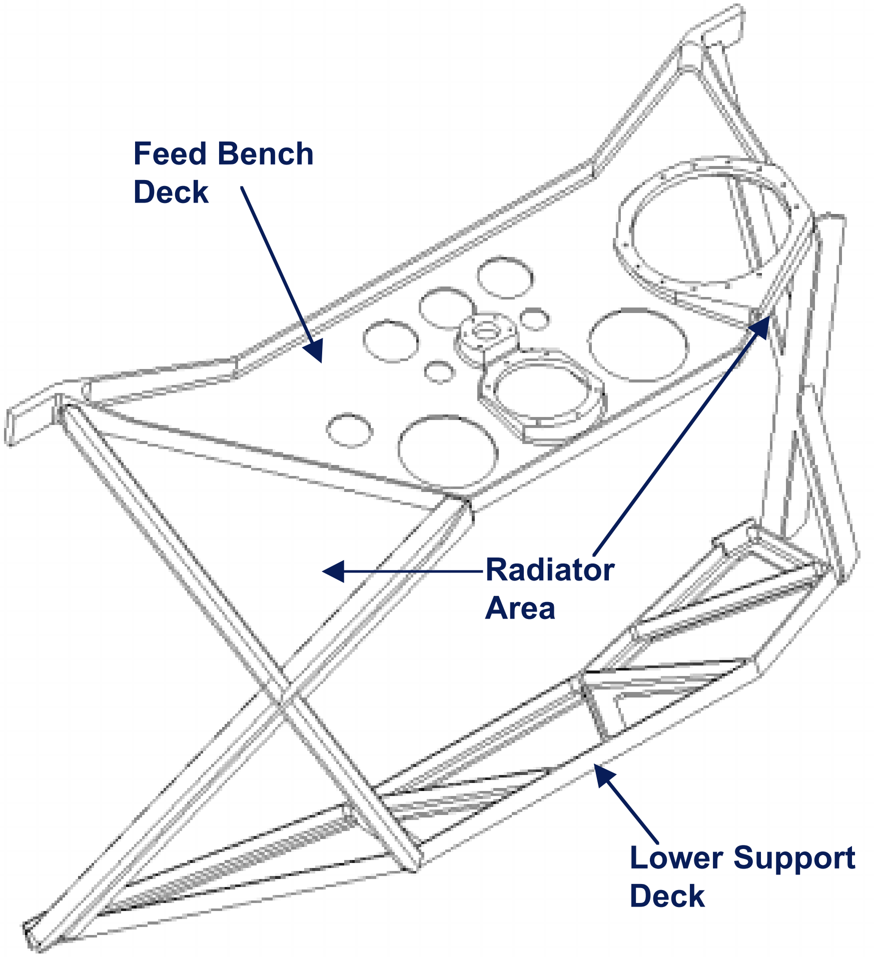
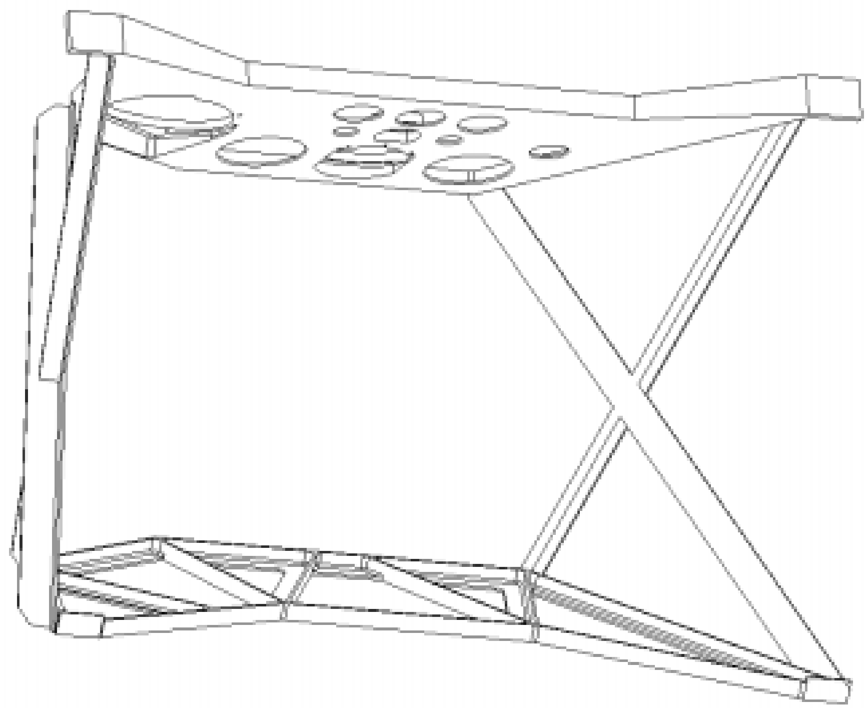
Feed Bench Structure

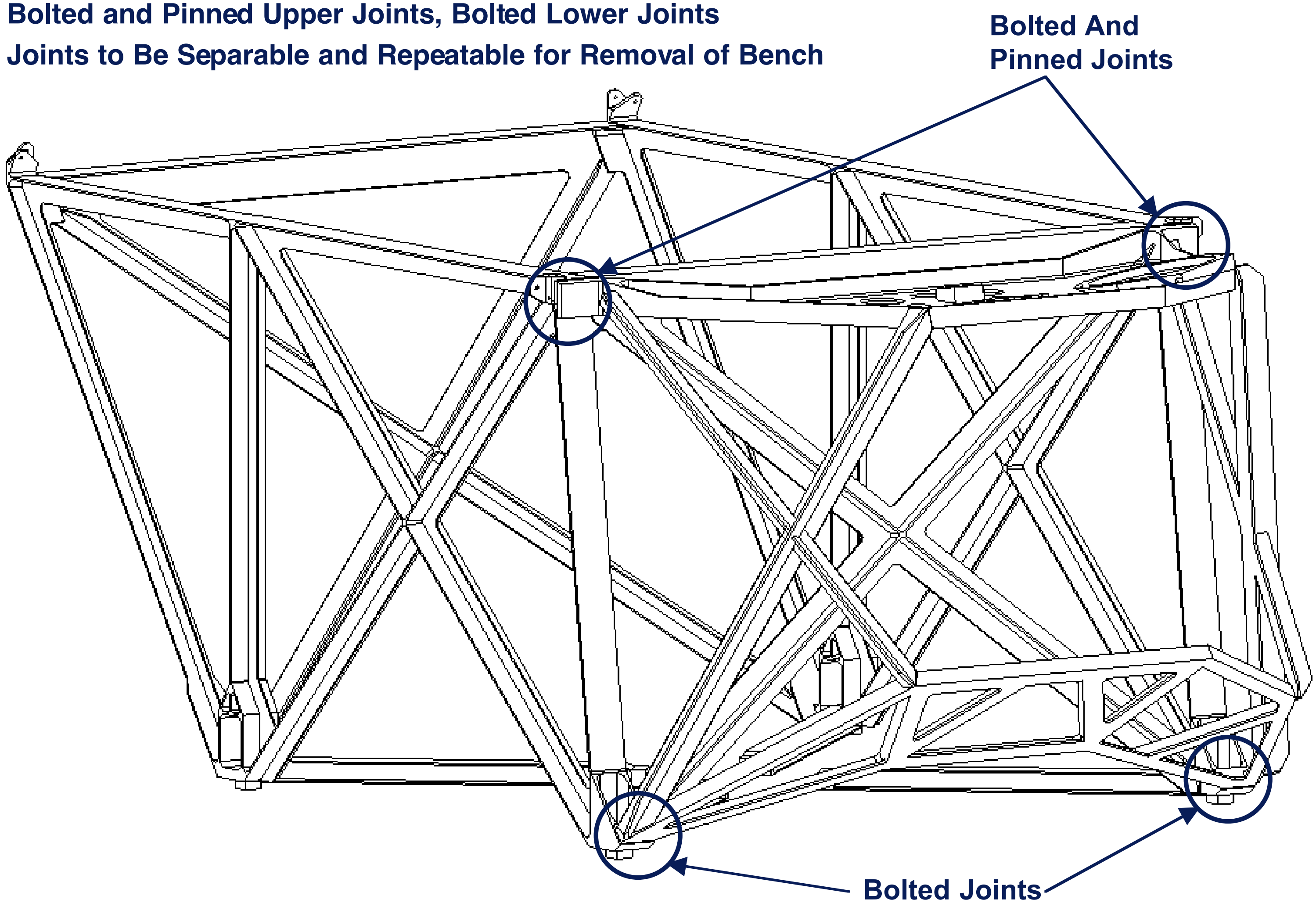
- All Aluminum Construction
- Solid Bench Deck With Egg-Crating for High Stiffness-to-Weight Ratio
- Bench Deck to Provide Axial Support Of Horn/OMT Assembly
- Lower Support Brackets Provide Lateral Support Of OMT



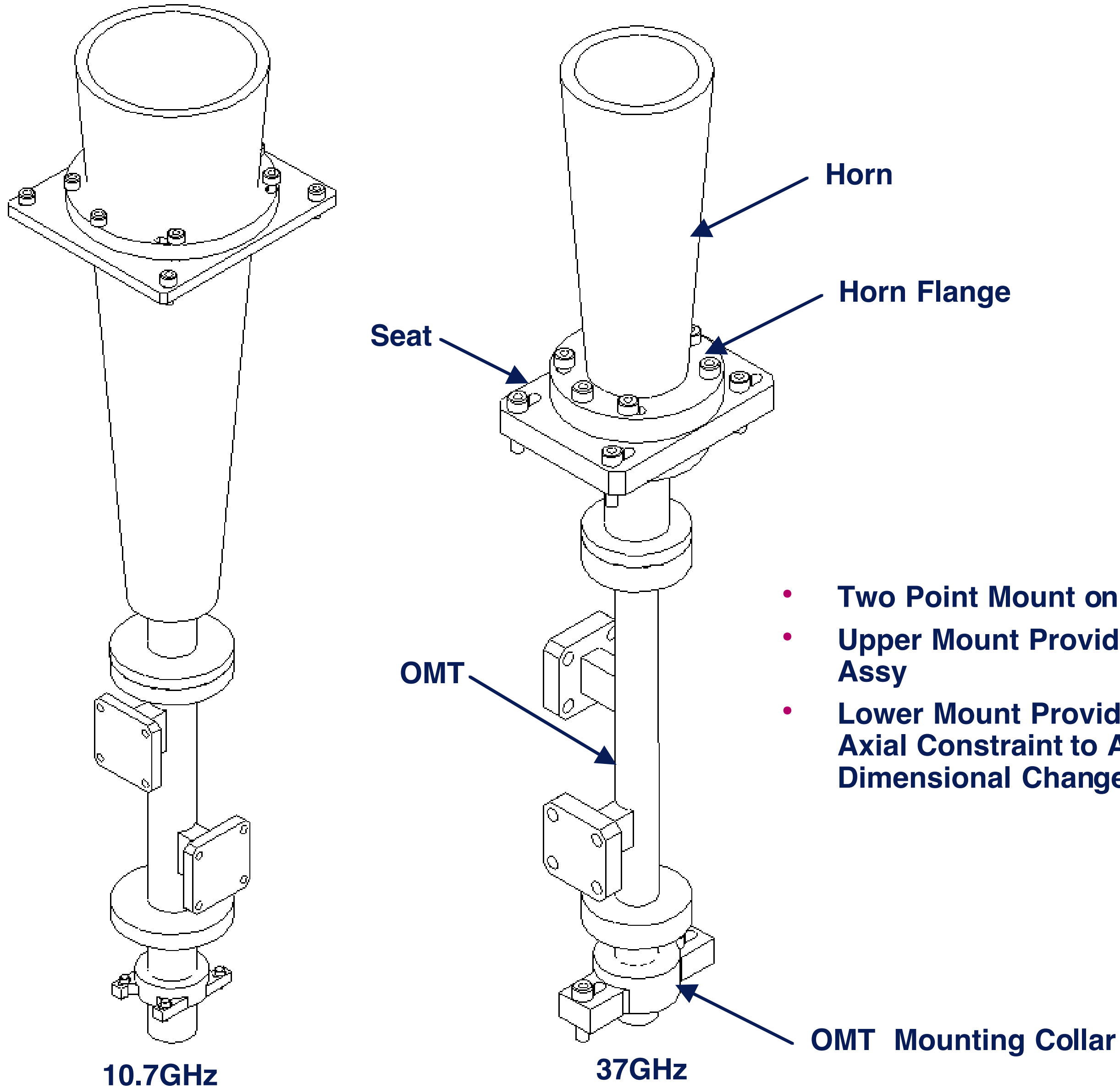


Feed Bench-to-Canister Interface

- Four Point Mount to Canister Frame
- Shim Spacer Between Bench and Canister to Provide Bench Lateral and Angular Adjustment (Not a Requirement)
- Bolted and Pinned Upper Joints, Bolted Lower Joints
- Joints to Be Separable and Repeatable for Removal of Bench



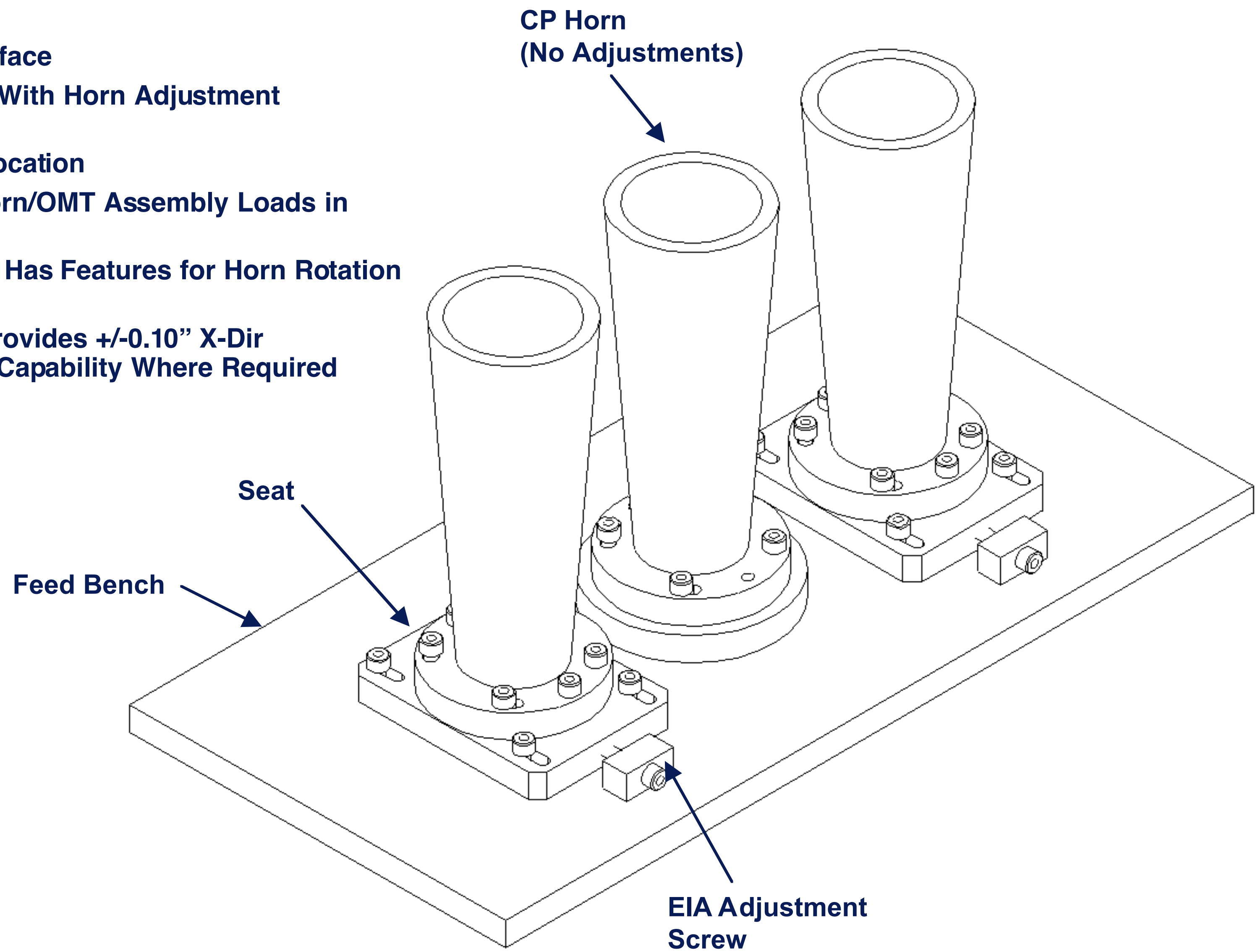
Feedhorn Mounting



- Two Point Mount on Each Feedhorn/OMT Assy
- Upper Mount Provides Full Constraint for Horn/OMT Assy
- Lower Mount Provides Lateral Constraint of OMT. No Axial Constraint to Allow Thermally Induced Dimensional Changes

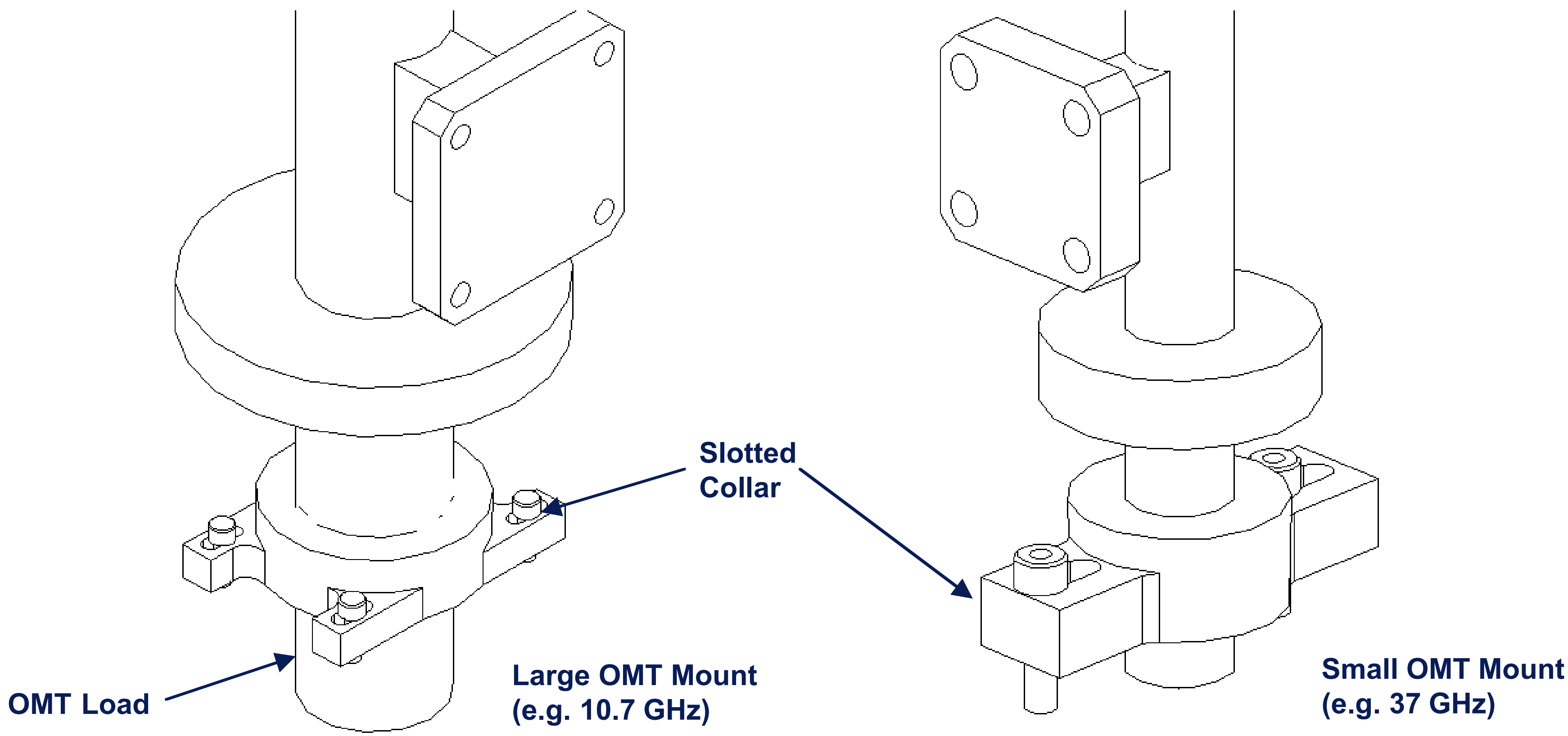
Feedhorn Mounting

- Horn-Bench Interface
  - Hard Mount With Horn Adjustment Capability
  - Sets Horn Location
  - Takes All Horn/OMT Assembly Loads in Horn Axis
  - Horn Flange Has Features for Horn Rotation Adjustment
  - Horn Seat Provides +/-0.10” X-Dir Adjustment Capability Where Required

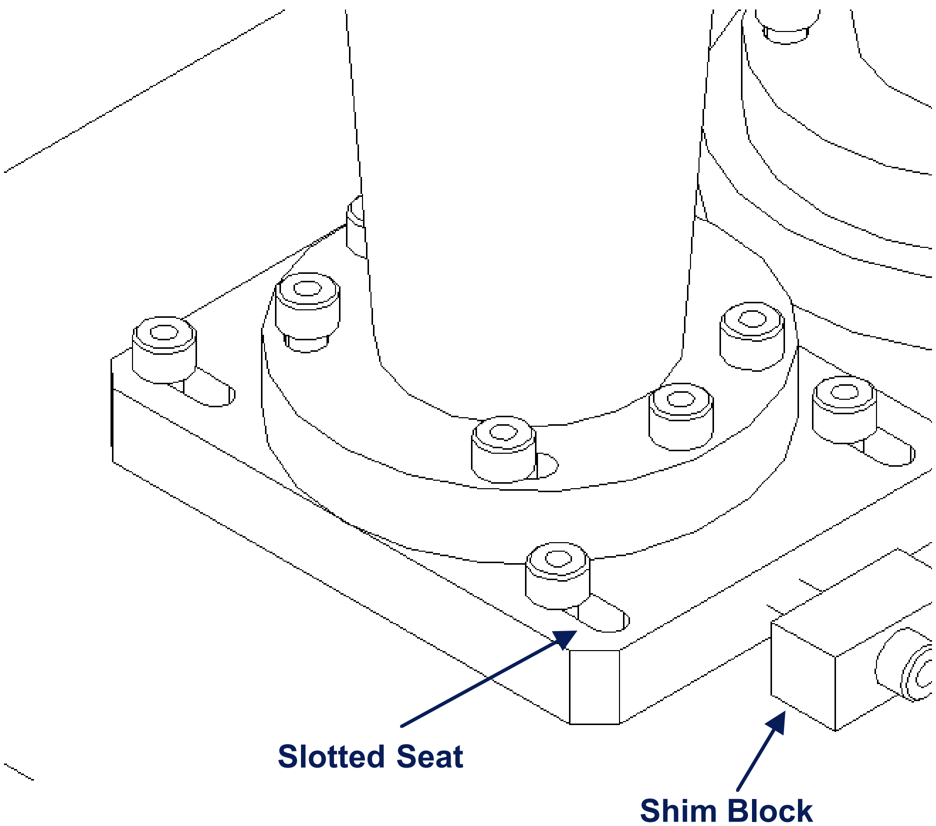


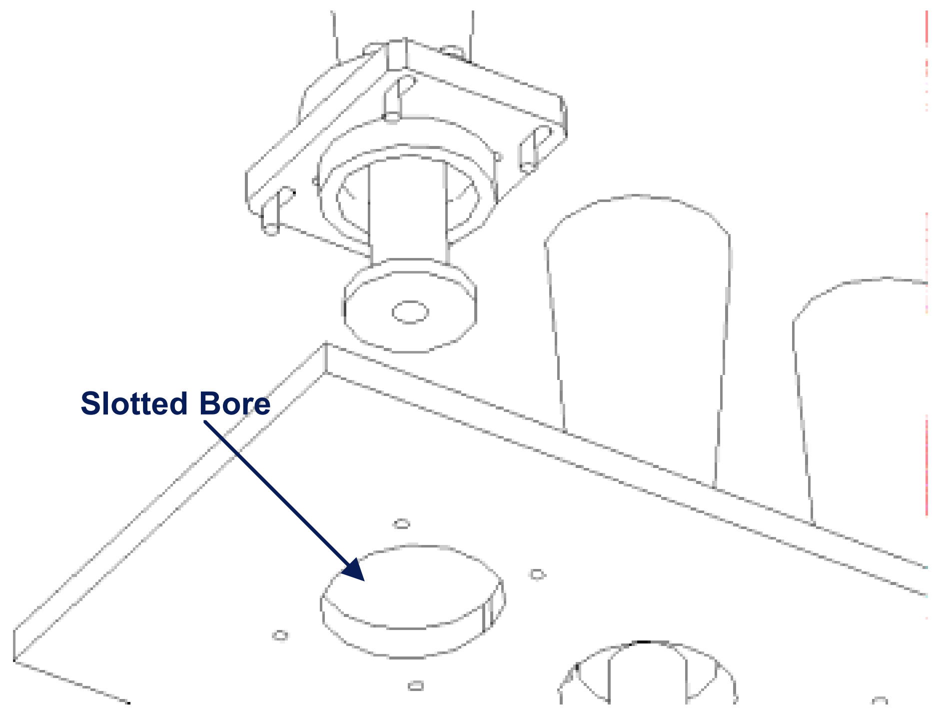
Feedhorn Mounting

- OMT-Bench Interface
  - Collar Captures OMT O.D. With Small Clearance for Axial Freedom
  - Interface Gasket Between Collar ID and OMT OD Provides Lateral Displacement Attenuation and Damping in Vibration
  - ±0.10” X-Dir Adjustment Capability Provided to Follow Horn Mount Adjustment Where Required
  - Interface Bracket Provides Load Path to Feed Bench Structure



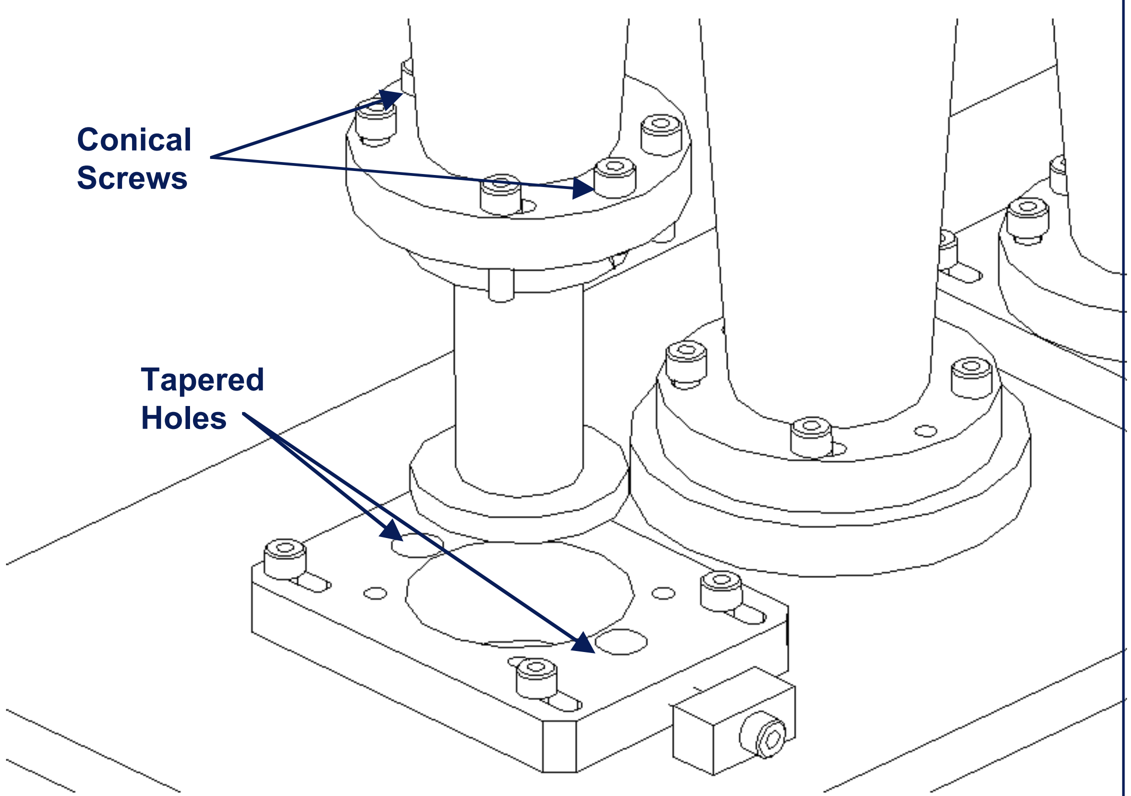
Feedhorn EIA Adjustment

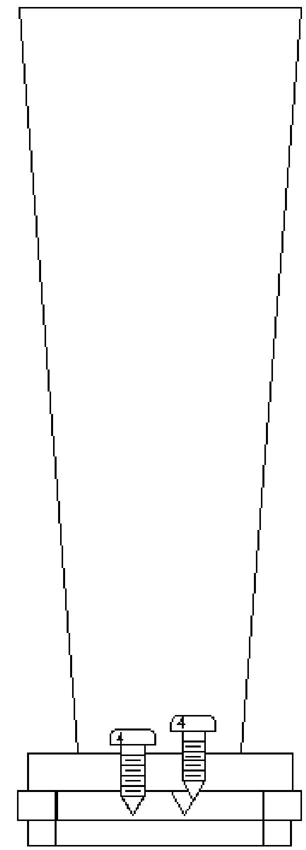




- Adjustment Capability Provides for Correction of EIA Errors in Offset Horns
- Seat Location Screw Adjustable
- Inserting Shim or Feeler Gage in .005” Increments Provides Location Tracking
- After Completion of Adjustment Procedure, Seat is Located With Permanent Shim Insert and Fixed With Locked Screw Adjuster

Feedhorn Rotation Adjustment

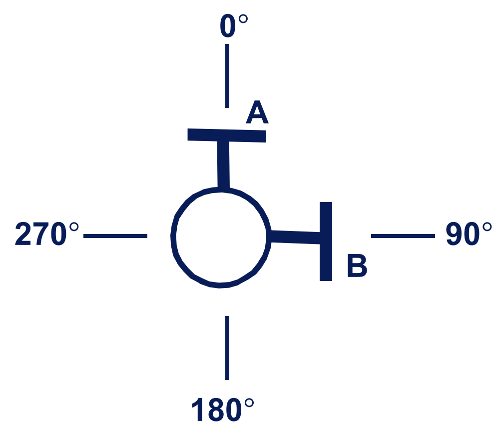


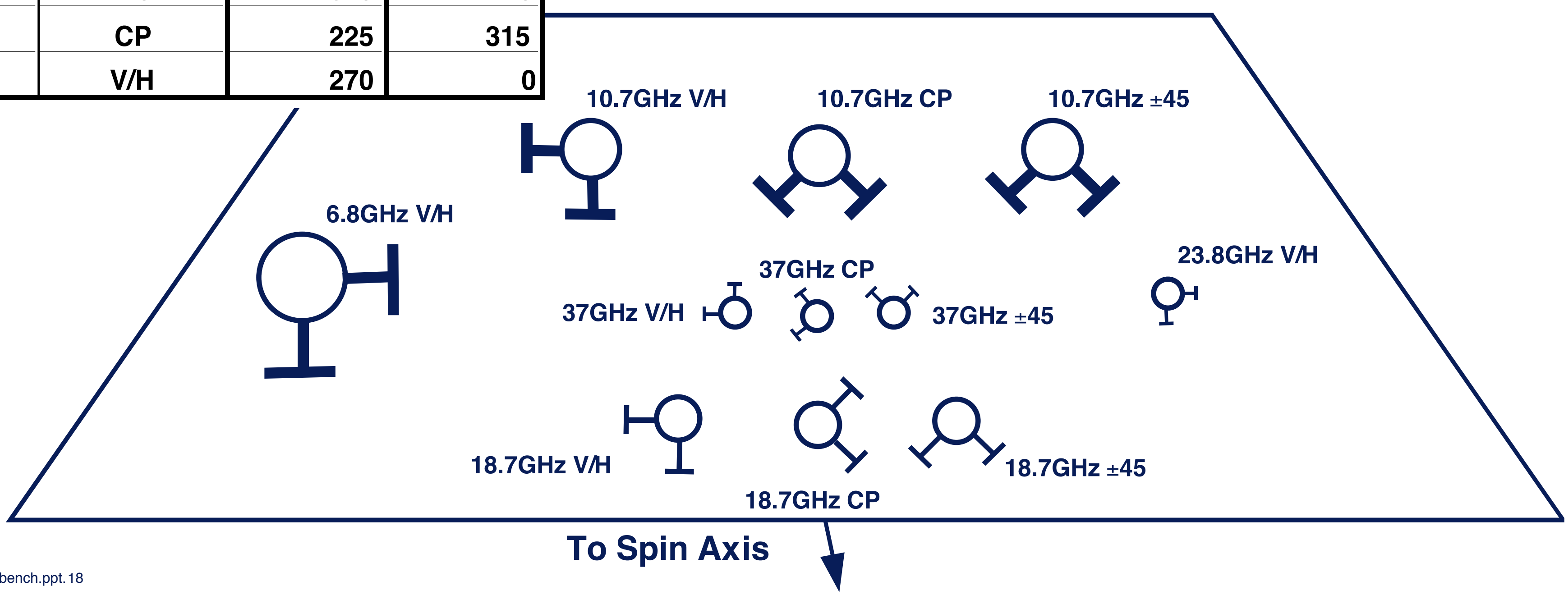


- Adjustment Capability Provides for Fine Tuning of Polarization Rotation Angle
- 0.015° Resolution Required
- >±2° Adjustment Range Provided for All Non CP Horns (Eight Horns Total)
- Rotation Effected With 60° Conical Screws Mounted to Horn Flange, Bearing on Tapered Holes in Horn Seat
- 32 Pitch Screws Provide 3° Screw Rotation Per 0.015° Horn Rotation on Smallest Horn (37 GHz)
- Multiple Conical Screw Sets Used On Largest Horns to Provide Range Without Increasing Tapered Hole Depth

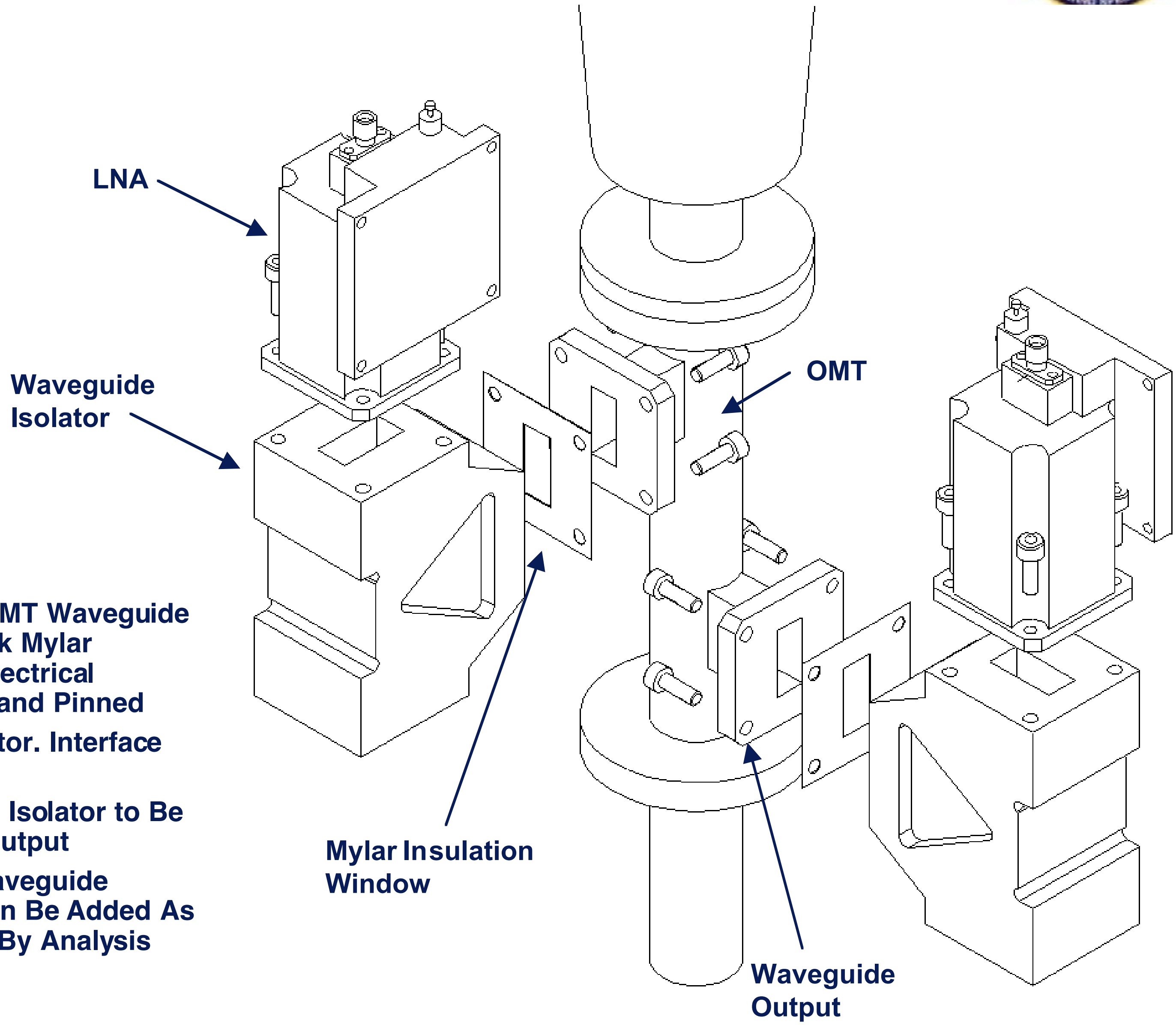
OMT Polarization Orientation

Feed Freq. (GHz)	Polarization	WG A Angle	WG B Angle
6.8	V/H	90	180
10.7	±45	135	225
10.7	CP	135	225
10.7	V/H	180	270
18.7	±45	135	225
18.7	CP	45	135
18.7	V/H	180	270
23.8	V/H	90	180
37.0	±45	315	45
37.0	CP	225	315
37.0	V/H	270	0





LNA And Isolator Mounting



- Isolator Bolts Directly to OMT Waveguide Output With 1 - 10 Mil Thick Mylar Insulator at Interface for Electrical Isolation. Interface Drilled and Pinned
- LNA Bolts Directly to Isolator. Interface Drilled and Pinned
- Launch Loads on LNA and Isolator to Be Taken Up By Waveguide Output
- Additional Stiffening of Waveguide Outputs (Gussets, Etc.) Can Be Added As Necessary As Determined By Analysis

Capabilities vs Requirements Summary

Capability	Requirement
Feed Bench Removable	No Requirement - Provides for Ease of Assembly and Contingencies
Feed Bench Shim Adjustable for Angle and ±X Location	No Requirement - Provides for Contingencies
Horns Adjustable in X-Dir By ±0.10” in 0.005” Increments	Horns Adjustable in X Dir by ±0.10” in 0.005” Increments
Polarized Horns Rotationally Adjustable By >±2° With a Resolution of Better Than 0.015°	Polarized Horns Rotationally Adjustable by at Least ±0.5° With a Resolution of 0.015°
1.5 ft^2 Radiator Area Provided. Additional Area Available if Required	Provide 1.5 ft^2 Radiator Area for Thermal Control of LNAs
Isolators and LNAs Mounted Directly to OMT Waveguide Outputs Providing Shortest Possible RF Path Length to LNA	Minimize Signal Path Length From OMT Waveguide Outputs to LNAs With Minimal Waveguide Extensions

Antenna Analysis and Predicted Performance

Lippincott
Bartlett

Antenna Analysis Approach

WindSat Antenna Analysis Performed to Predict Flight Performance

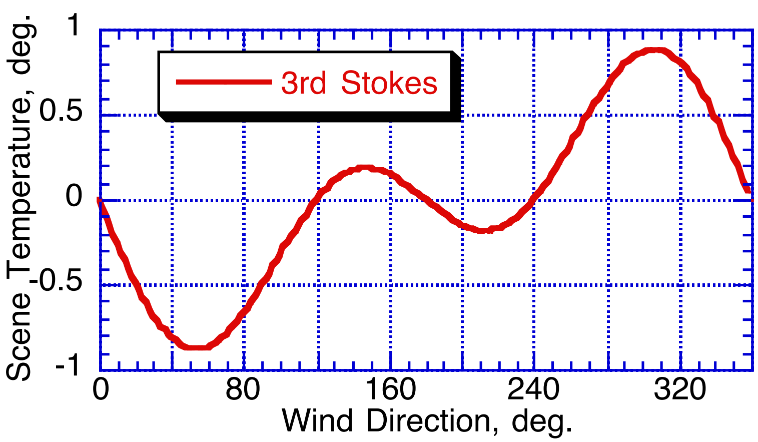
Specification	Analysis Approach	
Polarization Purity	POE Code	new analysis
Positional Tolerance of horns	POE Code	new analysis
Rotational Alignment of horns	POE Code	new analysis
Stokes Parameter Calibration	POE Code (range sensitivity analysis)	new analysis
Thermal-induced roughness on-orbit and rms roughness	Finite-element Analysis and OSUREF Modeling	new analysis
Beam Efficiency	OSUREF Code	new analysis
Beamwidth	OSUREF Code	completed at SRR
Phase Center Stability	POE Code	completed at SRR
Boresight Alignment	Mechanical Analysis	completed at SRR
VSWR	By Breadboard	completed at SRR
Insertion Loss	Spreadsheet Analysis	completed at SRR

Antenna Analysis: Stokes Coupling Summary (POE Code)

C_{vv}	C_{vh}	C_{vu}	C_{v4}
C_{hv}	C_{hh}	C_{hu}	C_{h4}
C_{uv}	C_{uh}	C_{uu}	C_{u4}
C_{4v}	C_{4h}	C_{4u}	C_{44}

Small Errors in 3rd and 4th Stokes Coupling Terms Create Large Errors in Scene Temperatures

$$T_{scene} = M^{-1} * T_{antenna}$$



Stokes Coupling Matrix Represents the Inherent Coupling of 4 Polarizations Into the Vertical, Horizontal, +/- 45 deg., And RCP/LCP (Circular Polarization) Polarized Horns

The Inverted Stokes Matrix Is Multiplied by the Antenna Temperatures (Powers) Obtained On-orbit to Determine the Scene Temperature

The Scene Temperature Varies With Wind Speed and Direction. Algorithms Are Used to Determine Wind Speed and Direction From the Scene Temperatures

Antenna Analysis: Stokes Coupling Inverted Matrices for Horn Cluster Configuration[1] (POE Code)

C_{vv}	C_{vh}	C_{vu}	C_{v4}
C_{hv}	C_{hh}	C_{hu}	C_{h4}
C_{uv}	C_{uh}	C_{uu}	C_{u4}
C_{4v}	C_{4h}	C_{4u}	C_{44}

Stokes Coupling (dB) 10.7 GHz:

0.01	-25.7	-30.9	-49.5
-25.8	0.01	-30.9	-46.2
-27.9	-27.9	0.02	-46.3
-40.3	-41.7	-37.4	0.0

Requirement is <-30 dB knowledge for V & H into 3rd and 4th Stokes terms

Stokes Coupling (dB) 18.7 GHz:

0.01	-25.0	-32.4	-54.3
-25.0	0.01	-36.0	-48.5
-29.5	-29.4	0.03	-48.1
-43.5	-46.2	-37.1	0.0

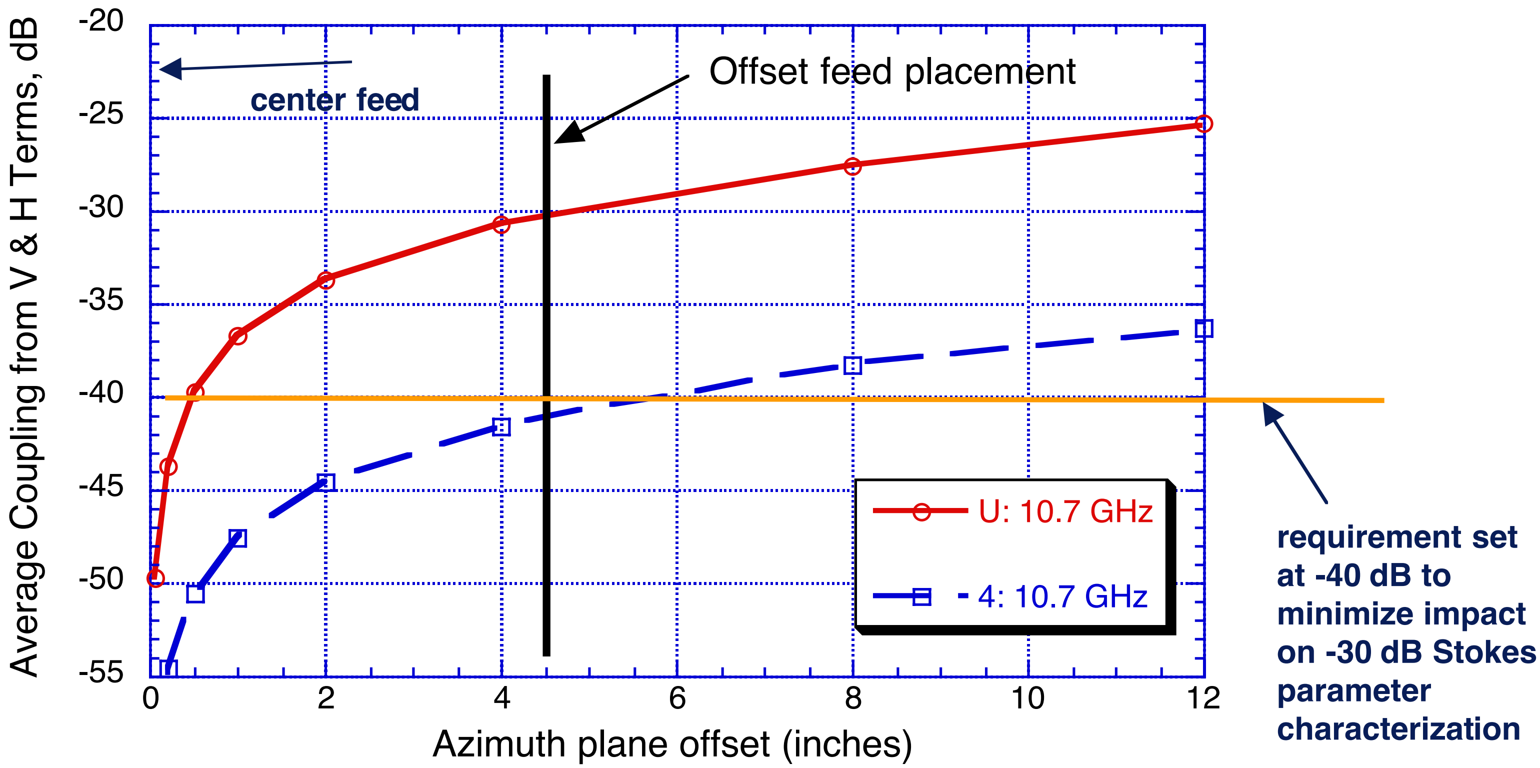
Stokes Coupling (dB) 37 GHz:

0.01	-25.8	-32.7	-63.2
-25.8	0.01	-32.7	-48.2
-29.7	-29.7	0.02	-69.3
-44.5	-52.5	-41.2	0.0

[1] Terms are generated from the Poe code, include polarization rotation error of 0.018 deg.

- Both +45/-45 and cp horns are in offset locations (for analysis purposes only; normally, the cp horn will have negligible coupling terms)
- 10.7 GHz is worst case, because although the offset distance in wavelengths is similar to 18.7 and 37 GHz, the angular offset is greater
- OSUREF code output was substituted for POE code reflector model. Similar results obtained.

Azimuth Plane Positional Accuracy for 3rd and 4th Stokes Terms (10.7 GHz)



- **Chart Indicates Tolerances for 3rd and 4th Stokes terms (for -40 dB Coupling):**
  - **for 10.7 GHz (U) Horn Should Be < 0.5"**
  - **for 10.7 GHz (4) Horn Should Be < 6"**

Note: Mechanical Tolerance Capability Is 0.017"

Azimuth Plane Positional Accuracy Needed to Reduce Stokes Coupling Terms and Stay within EIA Requirement

Freq. GHz	Term	Location	Allowable Offset Distance inches
10.7	U	offset	< 0.2
10.7	4	center	< 1.0*
37	U	offset	< 0.2
37	4	center	< 1.0*

* Allowable distance determined by EIA change with azimuth offset

- Mechanical Tolerance (0.017”) Exceeds Requirements for All Offset Horn Placements
- 18.7 GHz values will fall between 10.7 GHz and 37 GHz values

Elevation Plane Positional Tolerance Needed for Accurate EIA, 37 GHz*

- **Mechanical Tolerance of 17 mils Results in EIA (Earth Incidence Angle) Error of 0.0185 Degrees**
- **Requirement is 0.02 Degrees for Coalignment of Horn Feeds**
- **Mechanical tolerance exceeds requirement**

*** 37 GHz represents worst case**

Defocus Effects

- 10.7 And 18.7 GHz Feeds Need to Be Defocused in Order to Keep All the Feed Front Faces Aligned

- Analysis Shows Negligible Impact on Stokes Parameters, Beam Efficiency, and Spillover With the Required Defocus Distances

Freq. GHz	Position	Defocus distance in.	Δ Spillover Efficiency%	Δ Beam Efficiency %
10.7	center	0.33	0.03	0.009
10.7	offset	0.33	0.033	0.10
18.7	center	0.13	0.012	0.004
18.7	offset	0.13	0.012	0.003

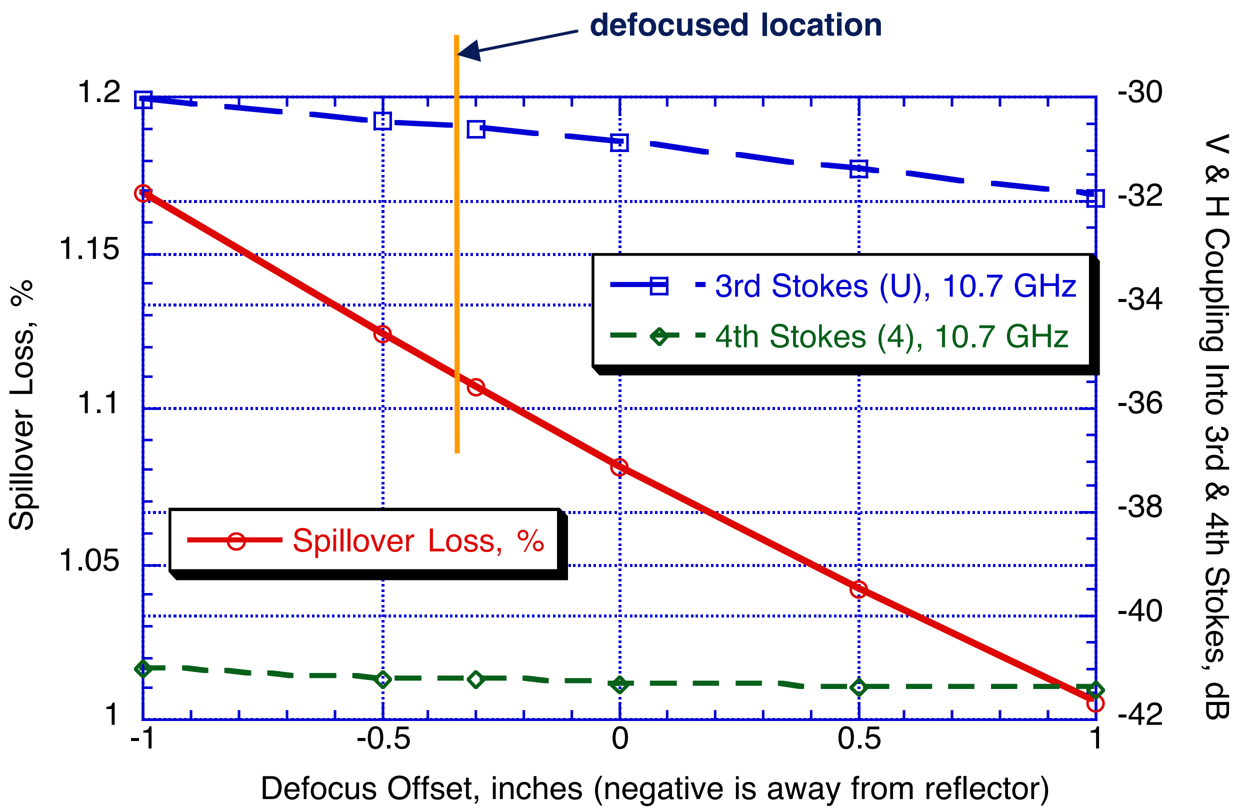
Defocus Effects on Stokes Coupling Terms

Freq. GHz	Position	Defocus distance in.	3rd Stokes Coupling, focused dB	3rd Stokes Coupling, defocused dB	4th Stokes Coupling, focused dB	4th Stokes Coupling, defocused dB
10.7	center	0.33	-156.9	-156.0	-152.9	-152.6
10.7	offset	0.33	-31.1	-30.6	-41.4	-41.3
18.7	center	0.13	-154.8	-155.5	-151.0	-151.8
18.7	offset	0.13	-34.2	-34.3	-44.9	-44.8

Stokes Coupling Terms Presented With No Rotational Errors Included

Defocus Has Minimal Effect on -30 dB Stokes Parameter Characterization

Defocus Effects



Defocus Effects on V & H Coupling into 3rd and 4th Stokes for Offset 10.7 GHz Feed (3.025,4.1) (Positive Defocus is Towards Reflector)

Tilt Error and Feed Polarization Rotation Error versus Range Accuracy

Feed Horn Rotation Error (θ) deg.	3rd Stokes Term Error *, dB 10LOG(sin(2θ))
1.02	-14.5
0.32	-19.5
0.10	-24.6
0.06	-26.8
0.032	-29.5
0.029	-30.0
0.023	-31.0
0.018	-32.0
0.014	-33.0
0.010	-34.5

range capability

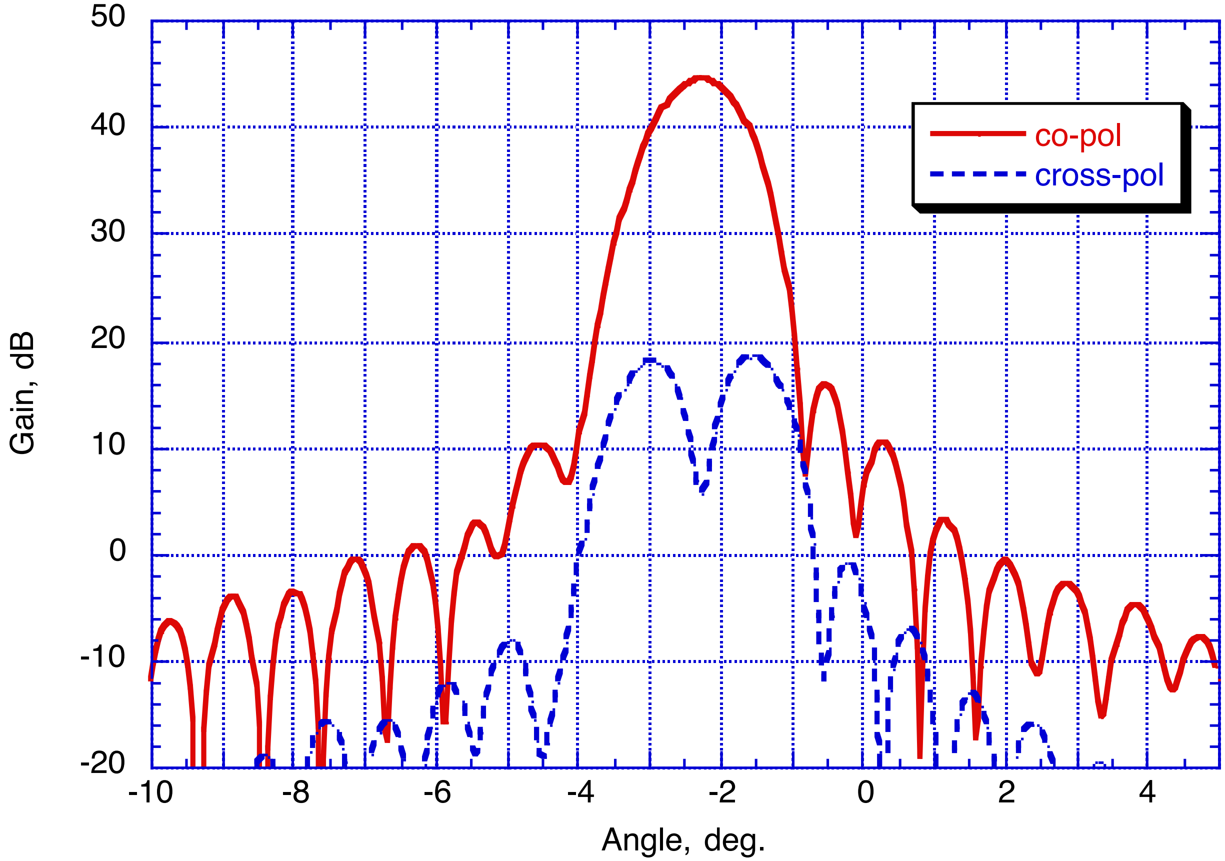
*** 4th Stokes Terms (CP Horns) Are Insensitive to Polarization Rotation**

Positional Accuracy Summary

- **Mechanical Tolerance Meets Requirements With Margin for All Horn Placements**

- **Tightest Requirement Comes From Horn Rotational Alignment for 45 Deg. Horns, However, Range Capability Meets Rotational Alignment Requirement**

Range Sensitivity Analysis: OSUREF Code Run Showing Cross-pol Lobe Structure

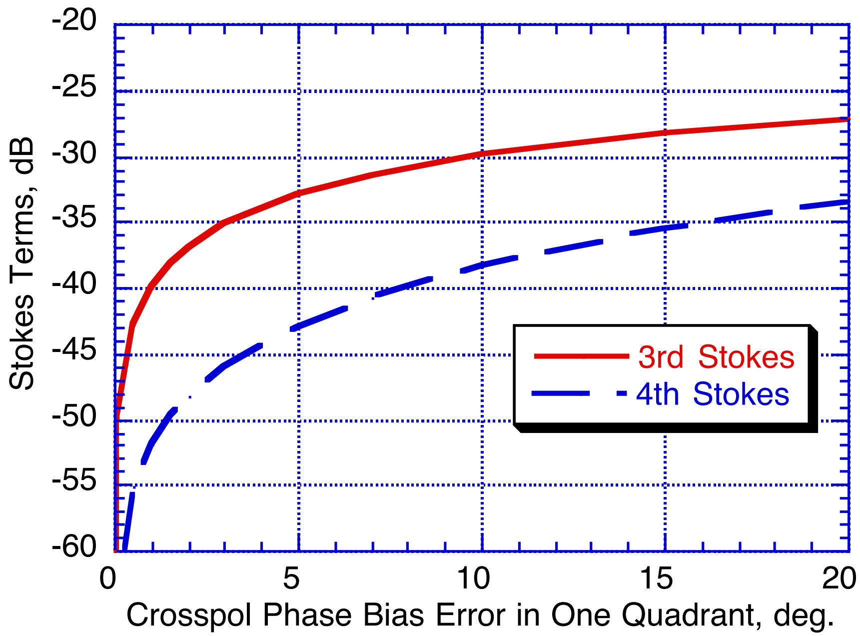


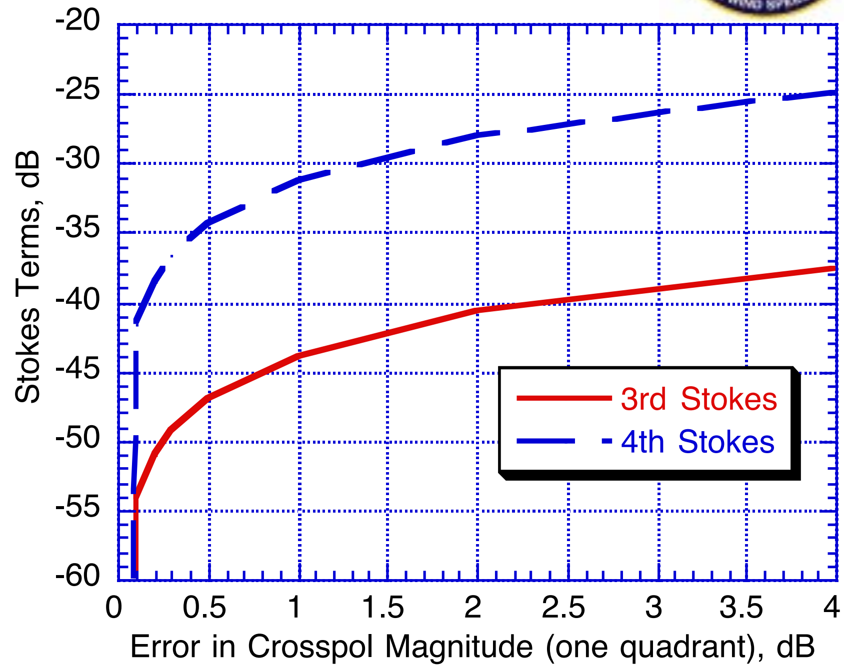
10.7 GHz, 3” Offset, 0.44 dB Difference in Height of Cross-Pol Lobes

C_{vv}	C_{vh}	C_{vu}	C_{v4}
C_{hv}	C_{hh}	C_{hu}	C_{h4}
C_{uv}	C_{uh}	C_{uu}	C_{u4}
C_{4v}	C_{4h}	C_{4u}	C_{44}

- **Cross-Pol Lobes for Centered Horns Are 180 Deg. Out of Phase, and Cancel Each Other Out. For the Offset Horns, Cross-Pol Lobes Are Imbalanced, and Do Not Cancel Each Other Out Completely. Magnitude of Stokes Coupling Terms Are Directly Related to Cross-Pol Lobe Imbalance.**

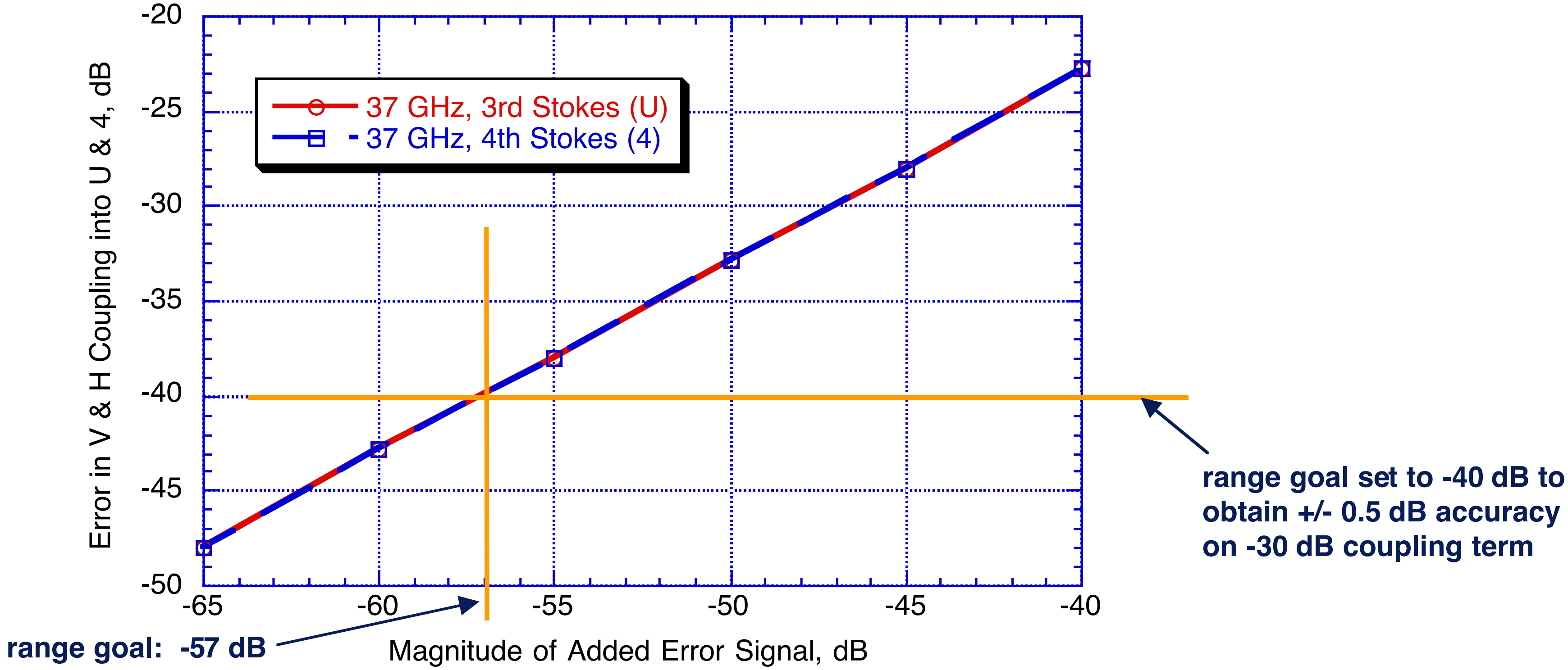
POE Code Sensitivity Analysis: Crosspol Terms





- **Stokes Parameters Need to Be Characterized to -30 dB**
- **Poe Code Was Modified to Analyze Impact of Range Bias Errors Over a Quadrant. To Keep Coupling terms Below -33 dB Range Error, the Following Are the Maximum Allowable Errors:**
  - **5 Degrees Crosspol Relative Phase Bias Error**
  - **0.7 dB Crosspol Relative Magnitude Error**
- **No Frequency Averaging, Errors Are Bias Errors, 37 GHz**

POE Code Sensitivity Analysis



- **Error in V & H Coupling Into U & 4 With Varying Error Signal Added Includes Averaging Over Bandwidth**
- **Similar Results are Obtained With 10.7 GHz**

Surface Tolerance Analysis

- **Ohio State Reflector Code Predicts RMS Surface Distortion Efficiencies Slightly Higher Than Ruze Equation Predictions**

RMS Surface Tolerance (λ)	RMS Surface Tolerance (mil)	Peak Gain (dB)	Ohio State Code Predicted Efficiency %	Ruze Equation Predicted Efficiency %
0.0	0.0	54.81	100.0	100.0
0.0094	3.0	54.75	98.63	98.62
0.0125	4.0	54.70	97.60	97.55
0.0157	5.0	54.65	96.38	96.18
0.022	7.0	54.49	92.90	92.64

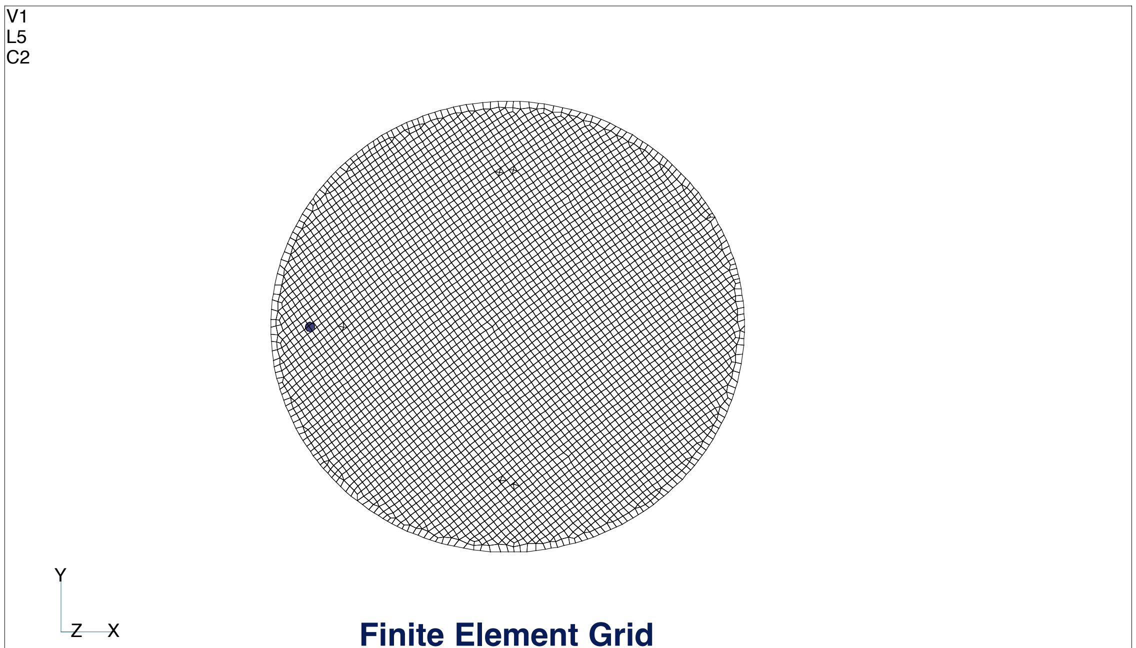
derived requirement (4 mil)

***Runs Done At 37 GHz (Worse Case)**

Ruze Equation Roughness Efficiency: $G = G_o \left[e^{\wedge}-(4\pi\sigma/\lambda)^{2}\right]$

Antenna Analysis: Surface Tolerance Analysis

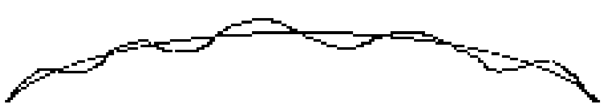
- **Ohio State Reflector Code Was Modified to Allow Input of WindSat Reflector Distortion Data From Thermal and/or Stress Analysis**
- **RMS Distortion Data Generated by Random Number or Measurement Can Be Added on Top of Thermal and Mechanical Stress Distortions to Determine Combined Effects**
- **Finite Element Files With 4500 Points Are Input**
- **Distortion Loss As Well As Pointing Errors Can Be Predicted**



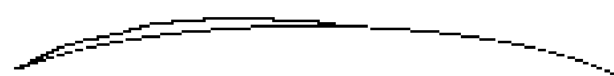
Finite Element Grid

Surface Roughness Analysis

- **Seven Thermal and Gravity Distortion Cases Were Run With the Ohio State Reflector Code**
- **All Seven Cases Had Small Mean and RMS Surface Tolerances, < 1.5 Mil**
- **Beam Efficiency Was Unaffected for All Seven Cases and Angle Errors Were Less Than 0.005 Deg.**
- **It Was Noticed That the Surface Distortions Due to the Thermal and Gravity Gradients Had Less Effect on Efficiency Than Would Be Predicted From a Straight Rms Distortion Prediction. This Is Because the Distortions Remain Constant Over Large Portions of the Dish. To Exemplify This, the Distortions Due to Gravity Gradients Were Multiplied to Provide an Overall RMS Surface Accuracy of 6 Mil. The Efficiency for This Case Was 98.0% Compared to 94.5% For a Random RMS Surface Accuracy of the Same 6 Mil.**



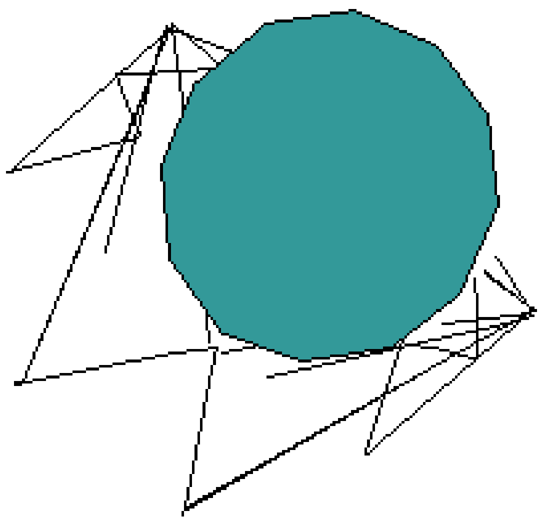
rms reflector distortions (magnified)

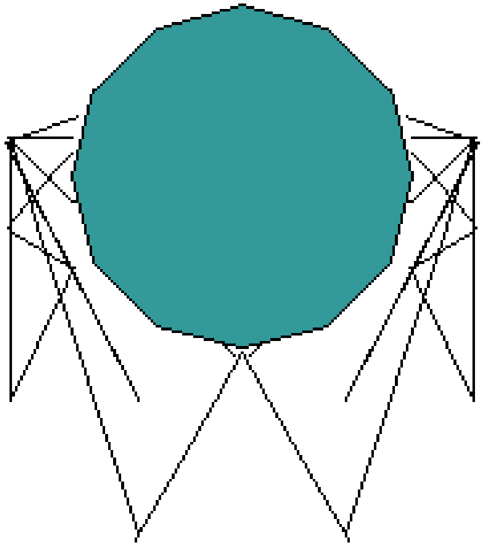


thermal or gravity gradient reflector distortion

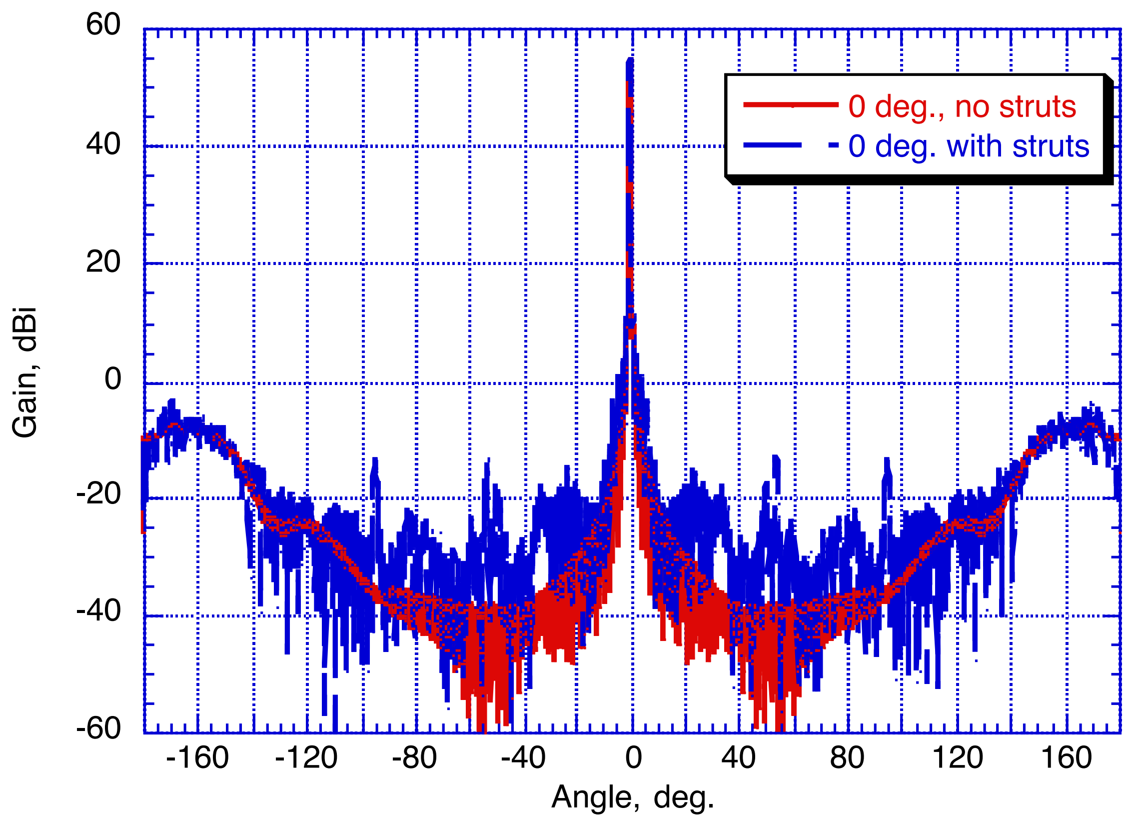
Antenna Analysis: Struts

- An Analysis of the Impact of Struts on Beam Efficiency Was Performed to Give Guidance to the Mechanical Design Team on the Strut Design. The Ohio State Reflector Code Used to Predict Efficiency Loss Due to 24 Struts
- Circular Cross-Section Struts Were Used. Extra Moldings to Deflect Fields Away From the Reflector and Feeds Will Improve Results



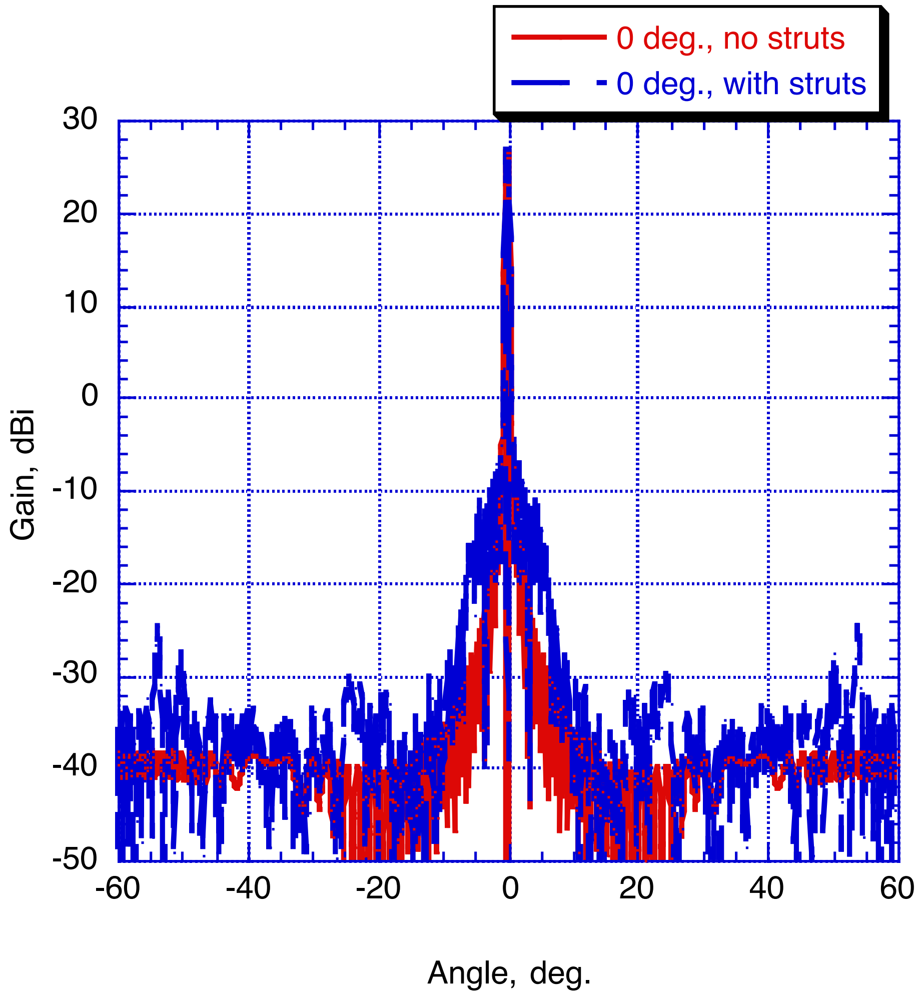


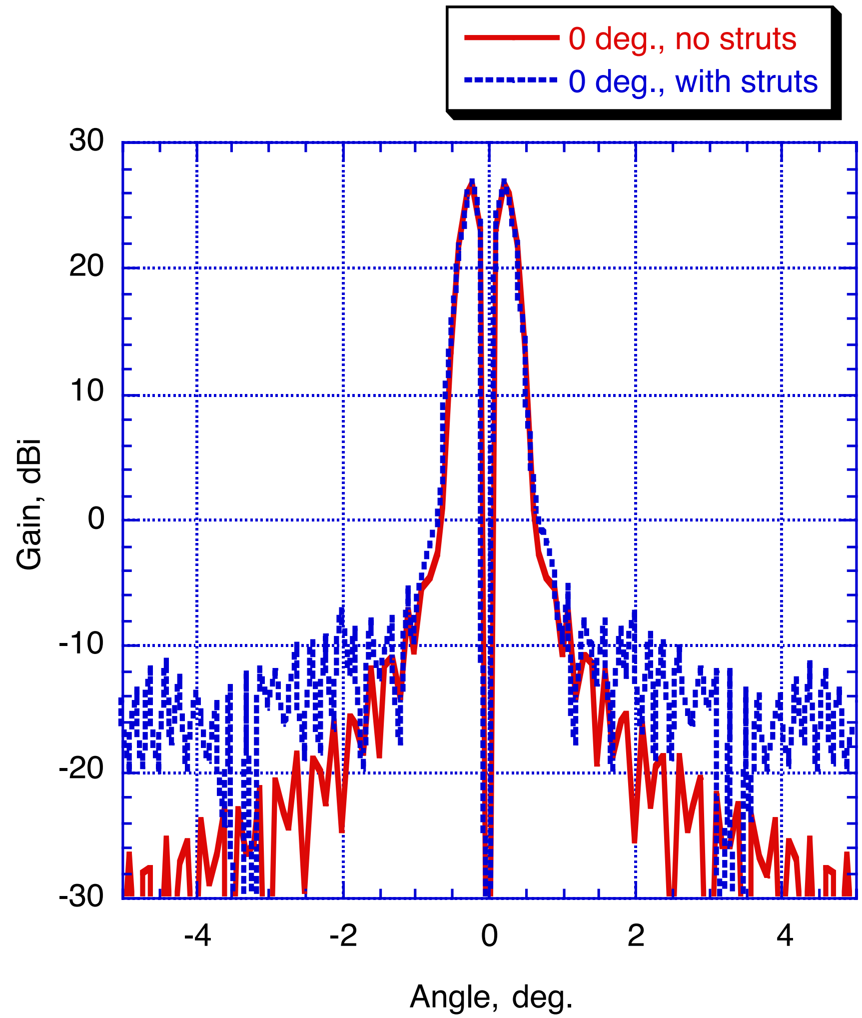
Strut Scattering Analysis: Copol Pattern



37 GHz, 1.5" Diameter Struts

Strut Scattering Analysis: Crosspol Pattern

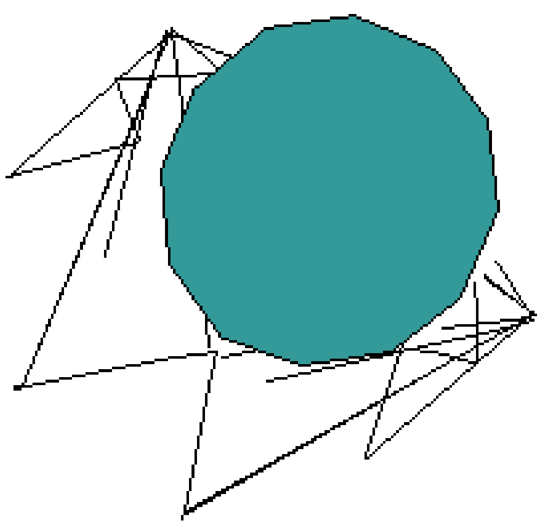


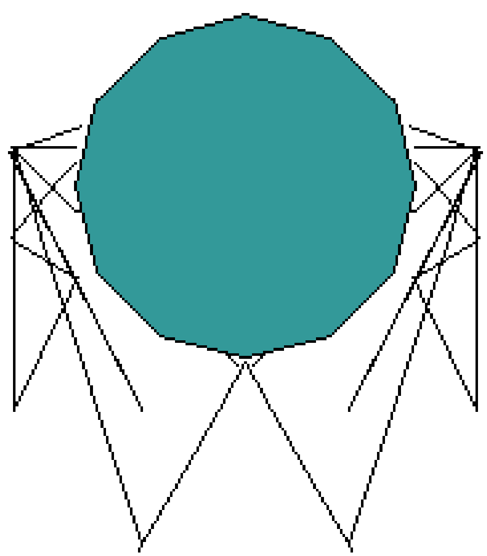


37 GHz, 1.5" Diameter Struts

Strut Scattering Analysis

Strut Geometry	Beam Eff. w/ Struts %	Beam Eff. No Struts %	Change in Beam Eff. %
24 Struts (1.25" dia.) 37 GHz	97.95	98.31	-0.36
24 Struts (1.5" dia.) 37 GHz	97.88	98.31	-0.43
24 Struts (2.0" dia.) 37 GHz	97.73	98.31	-0.58
24 Struts (2.0" dia.) 10.7 GHz	97.67	98.27	-0.60





Efficiency is Over 2.5 x 3 dB Beamwidth

Beam Efficiency Summary

	Efficiency %
Cross-polarization	99.1
2.5 Beamwidths	99.2
Struts	99.6
Surface Roughness (5 mil)	96.2
Total:	94.2

goal 95 %

- 37 GHz, 1.25" Struts (24 struts)

37 GHz Is Worst Case, Surface Roughness Efficiency Increases to 99.1% For 18.7 GHz

Breadboard Range Measurement Objectives

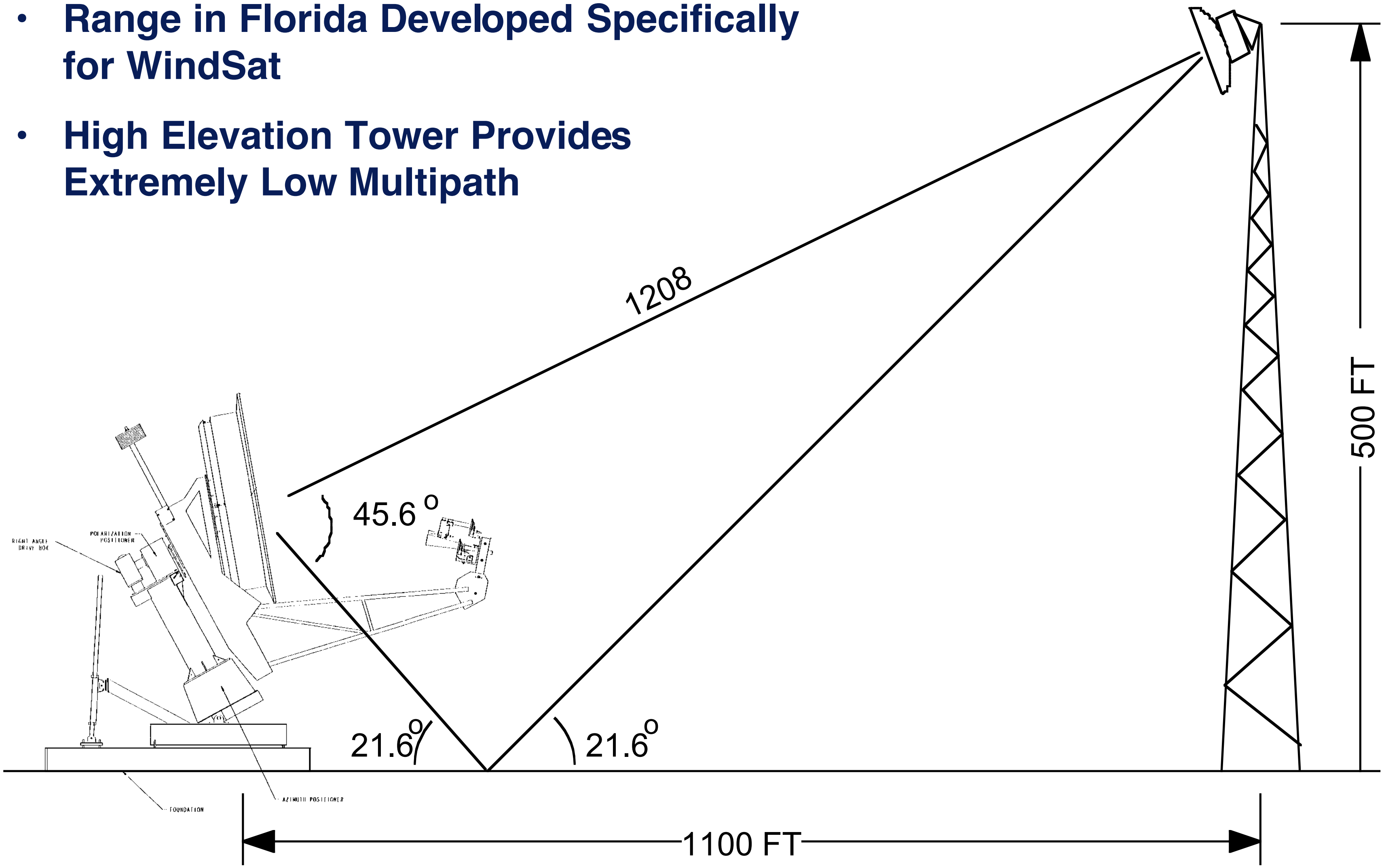
- Demonstrate Range Capability to Provide Antenna Pattern Characterization
- Demonstrate That Range Measurement Errors Are Lower Than -57 dB Requirement for Verification and Calibration of Flight Antenna
- Validate Antenna Performance Predictions of Analysis Programs
- Demonstrate That High-Isolation 37 GHz Feed Is Obtainable

Breadboard Test Status

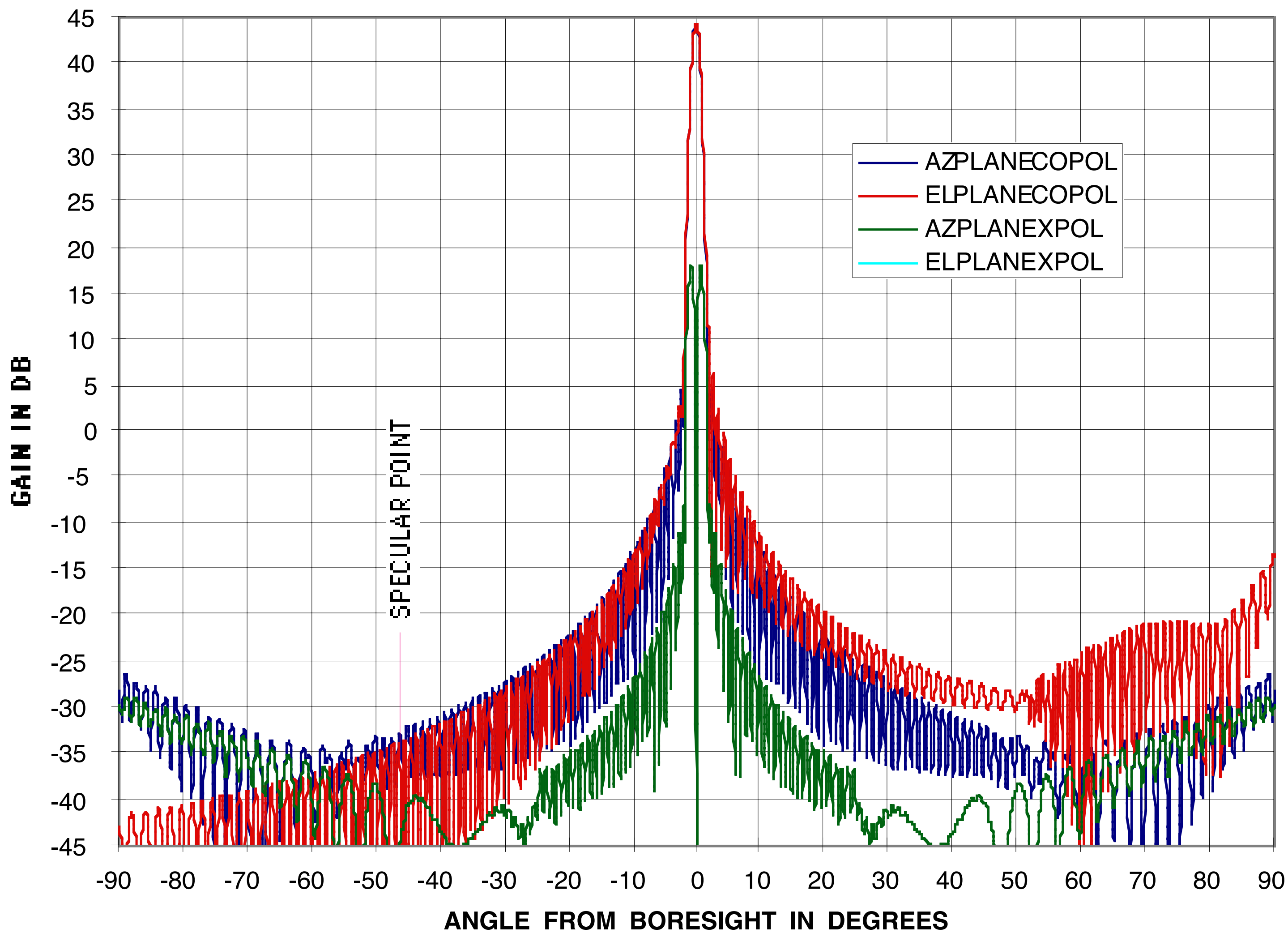
- **Precision Range Measurement Capability Demonstrated at 10.7 GHz**
- **Performance Predictions of Analysis Program Validated**
- **37 GHz Range Measurements Not Started, Feed Built and Tested**

Antenna Test Range

- **Range in Florida Developed Specifically for WindSat**
- **High Elevation Tower Provides Extremely Low Multipath**

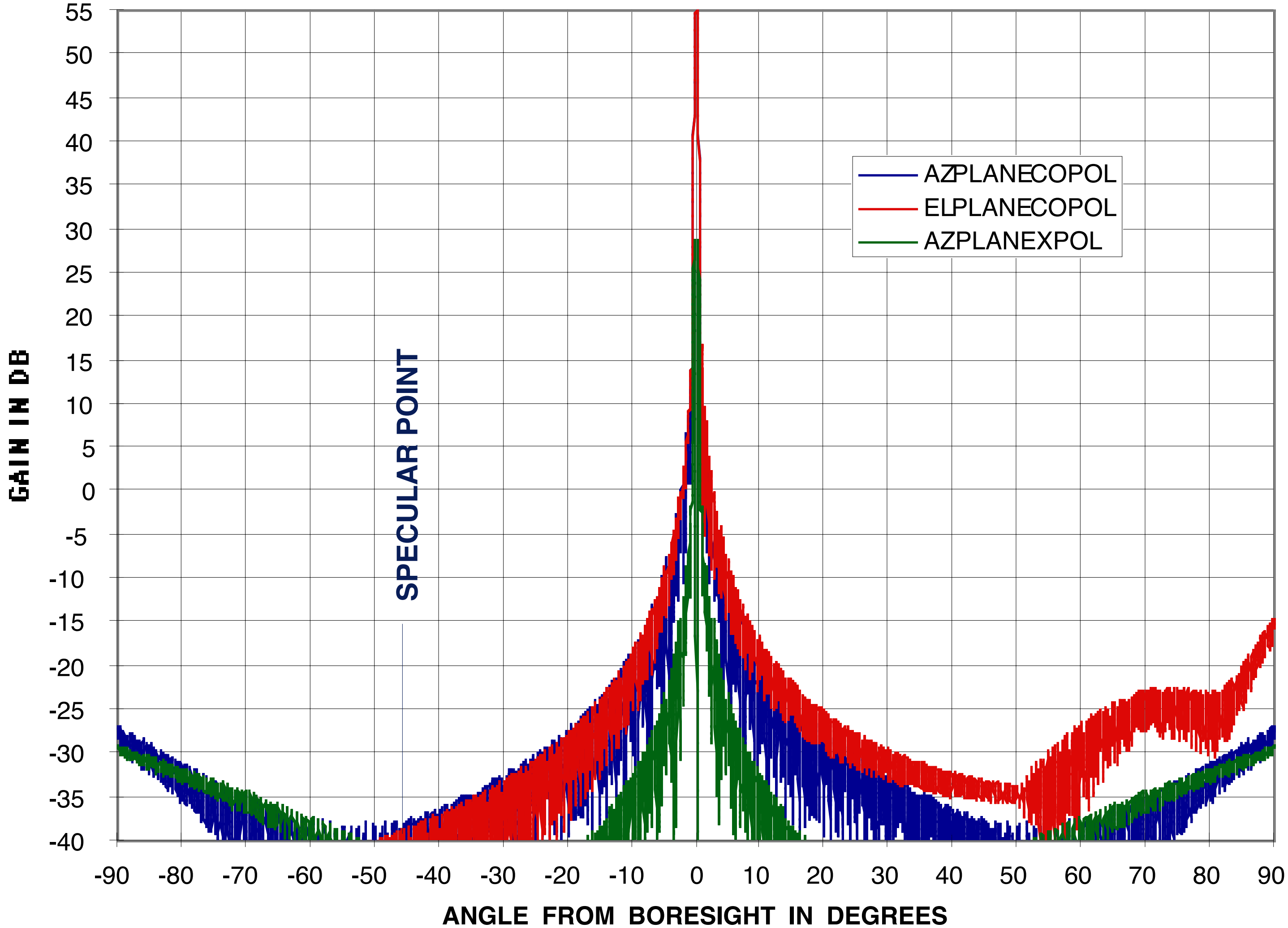


WindSat 10.7 GHz Wide Angle Pattern



At specular point on antenna range, antenna pattern down -77 dB (demonstrates multipath error budget met)

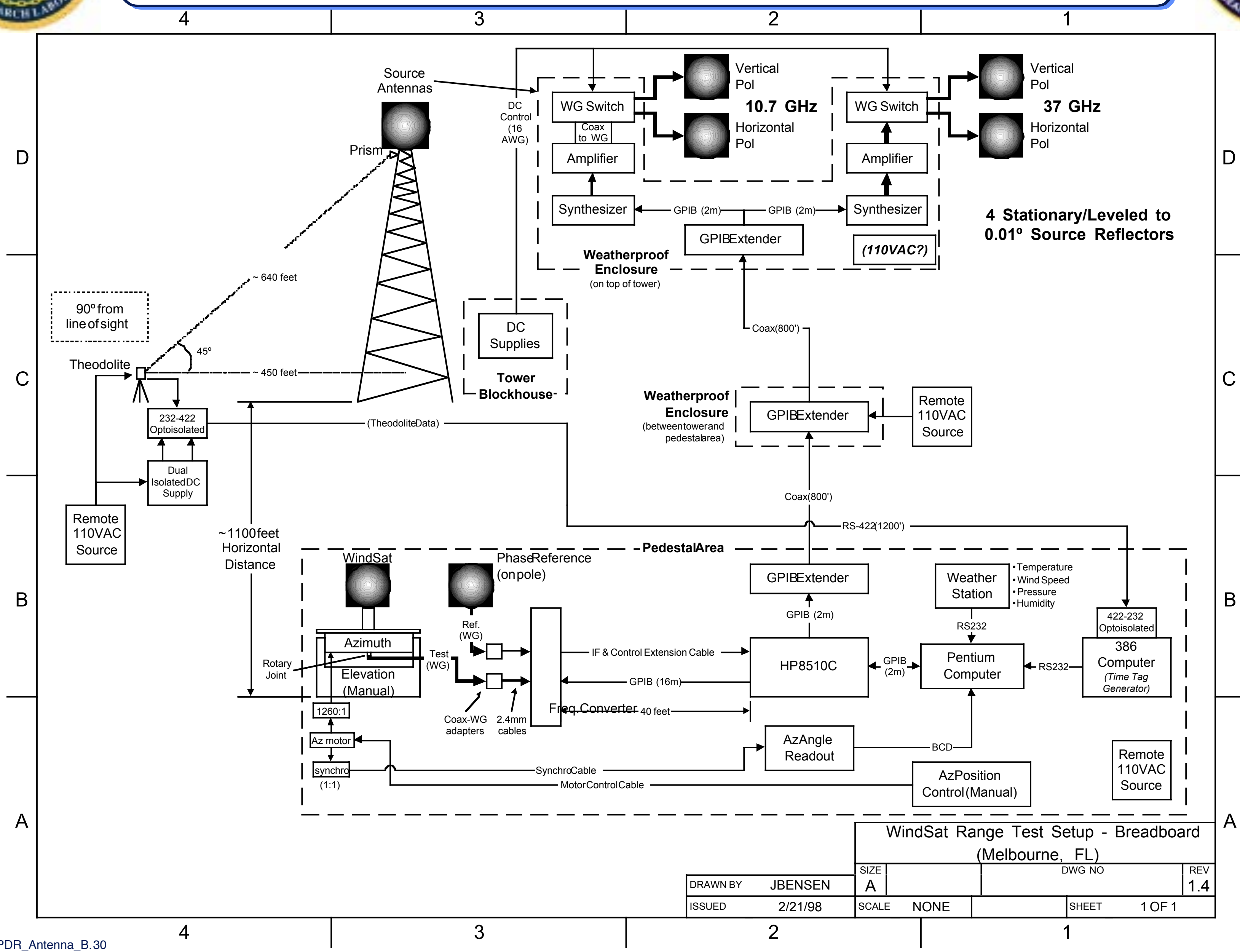
WindSat 37 GHz Wide Angle Pattern



At specular point on antenna range, antenna pattern down -93 dB (demonstrates multipath error budget met)

Antenna Test Range Video

Antenna Test Range Block Diagram



WindSat Breadboard Antenna
On Test Range

10.7 GHz Transmit Antenna With Polarization Grid

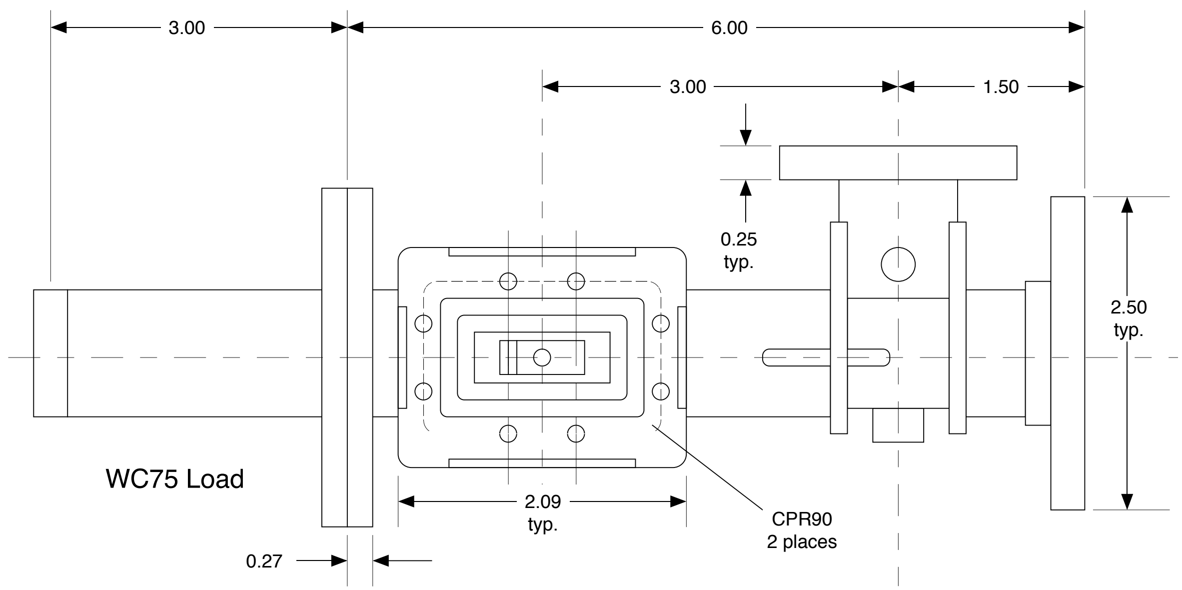
Range Measurement Cross-Pol Error Budget

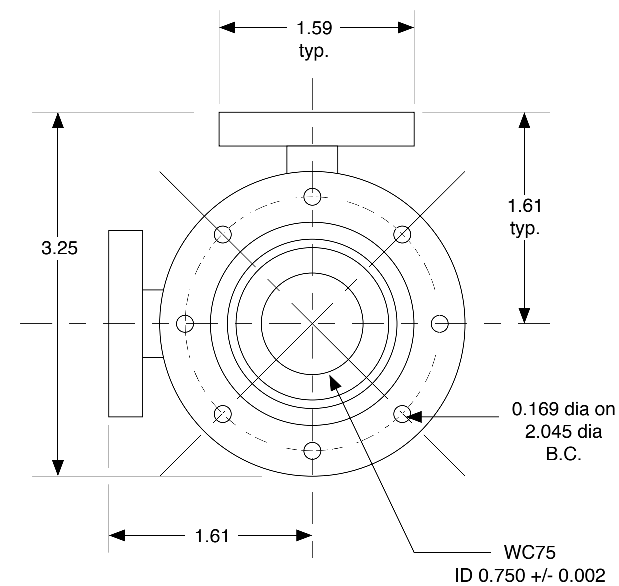
	Breadboard	End Item
• Range Reflections	-70 dB	-70 dB
• Orthomode Isolation	-65 dB	-65 dB
• Transmit Antenna	-73 dB	-73 dB
• NIST POL STD (30 Arc Sec)		-77 dB
• Inclinometer (0.002°)	-89 dB	
• POL Encoder 0.001°)		-95 dB
RSS	-63 dB	-63 dB
Requirement:	-57 dB	-57 dB

Range Accuracy

- 45.6 Degree Angle To Specular Reflection Area Gives Extremely High Rejection Of Multipath
- High SNR Capability Makes Possible Repeatable Cross-Pol Null Measurements Lower Than -70 dB
- Antenna Range Provide < -73 dB Transmit Antenna Crosspol
- Transmit Antenna Polarization Grids Set Orthogonal Using Precision 90 Degree Shop Tool And Precision Inclinometer (0.002 Degree Resolution). Confirmed by Consistently Measuring < -70 dB Null Depths in Crosspol Patterns.
- Range Measurements Demonstrate Feed Polarization Isolation of Better Than -65 dB
- Tests Performed at Night to Minimize of Thermal and Wind Induced Variations

Breadboard 10.7 GHz Orthomode





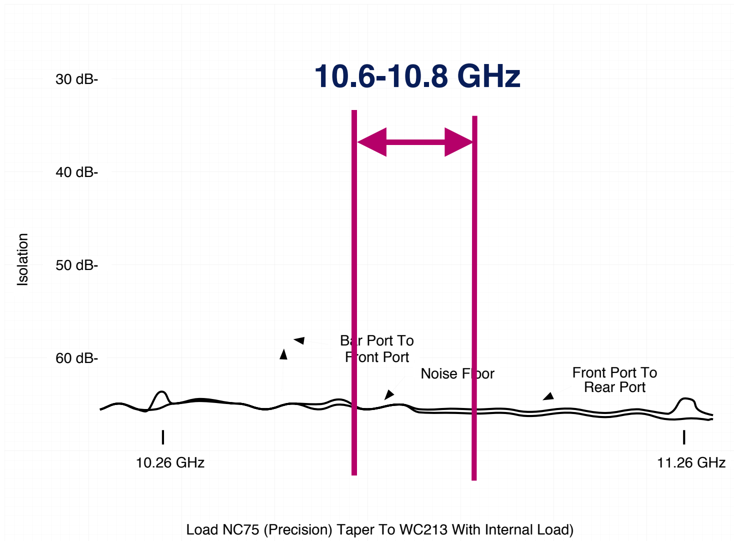
Swivel Flange

Notes:

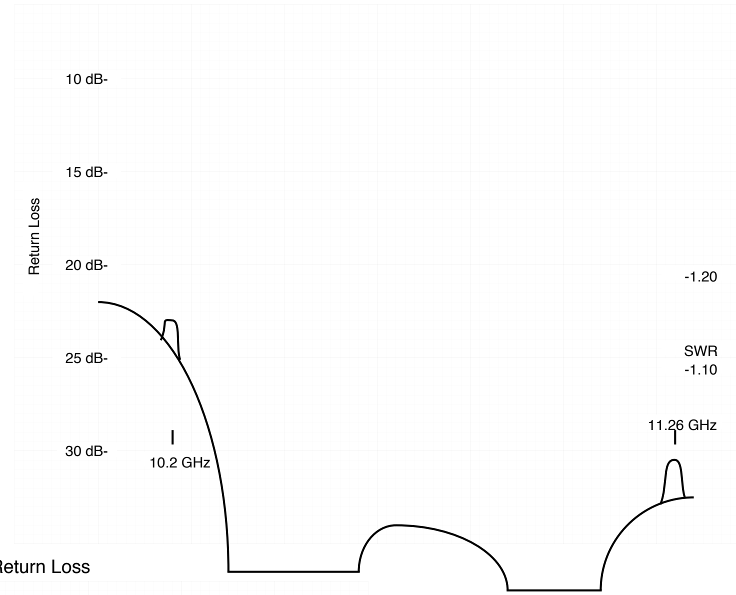
1. Frequency Range 10.7 +/- 0.2 GHz
   - a. Return Loss 26 dB (SWR 1.1)
   - b. Isolation -40 dB
2. Finish-Copper Iridite

10.7 GHz Orthomode Performance

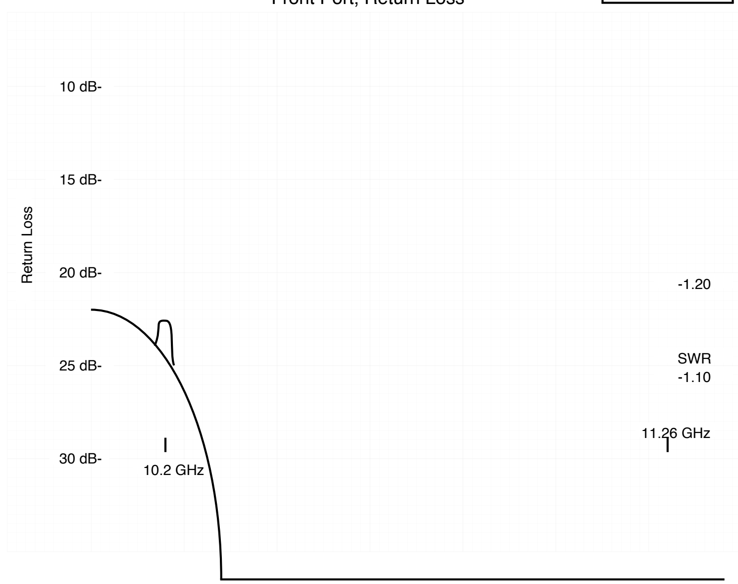
Isolation



Rear Port, Return Loss



Front Port, Return Loss

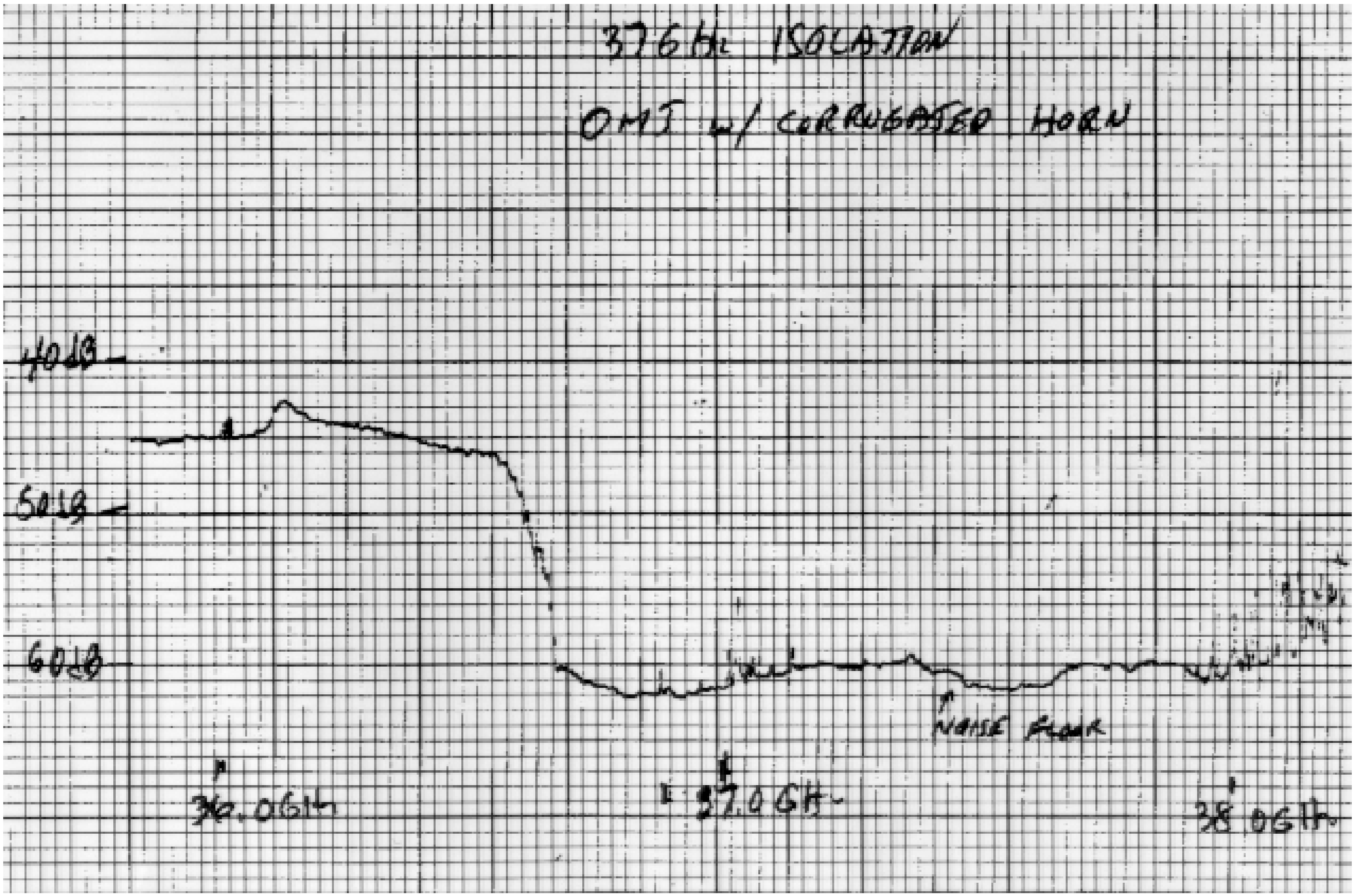


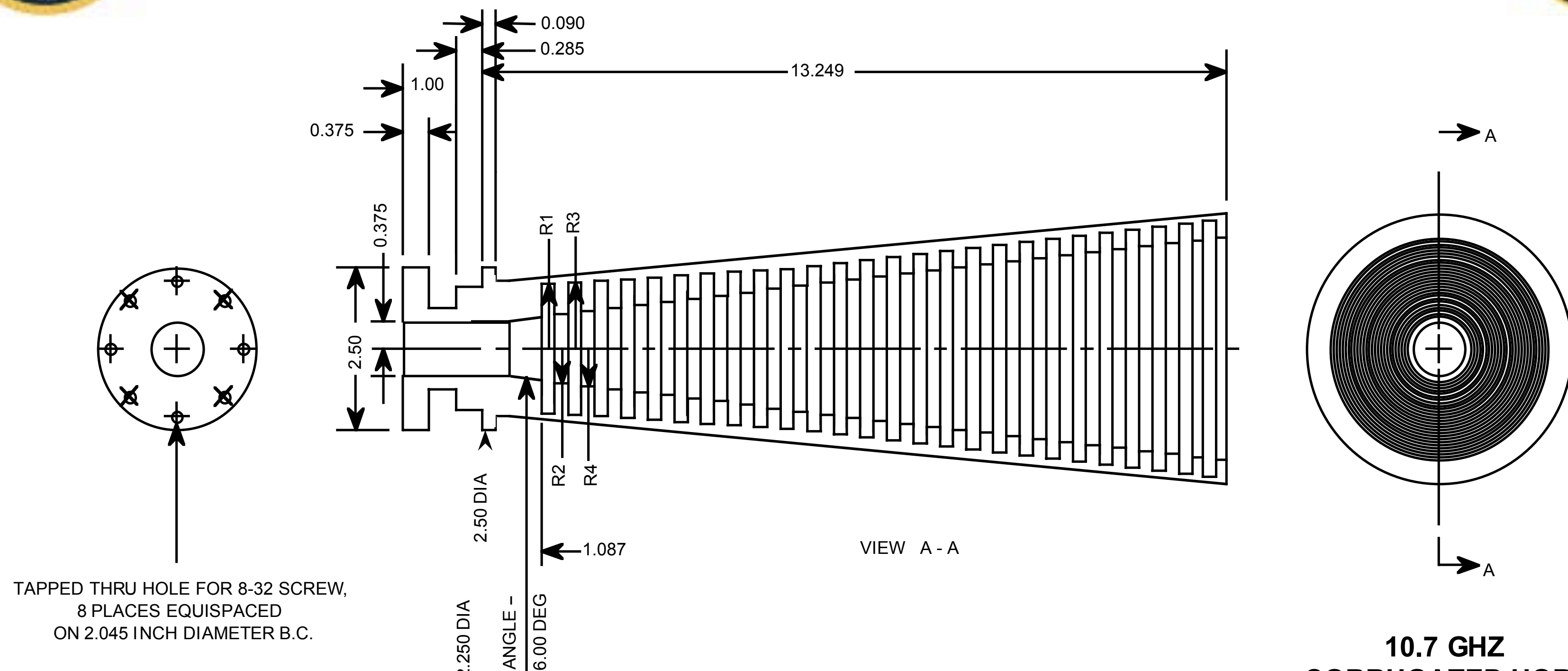
Derived Requirements:

-65 dB isolation

VSWR 1.1

37 GHz Orthomode Performance





R1	1.081	R20	0.928	R39	1.694
R2	0.522	R21	1.400	R40	1.379
R3	1.107	R22	0.973	R41	1.726
R4	0.567	R23	1.433	R42	1.424
R5	1.140	R24	1.018	R43	1.759
R6	0.613	R25	1.466	R44	1.469
R7	1.172	R26	1.063	R45	1.791
R8	0.658	R27	1.498	R46	1.514
R9	1.205	R28	1.108	R47	1.830
R10	0.703	R29	1.531	R48	1.559
R11	1.237	R30	1.153	R49	1.875
R12	0.748	R31	1.563	R50	1.604
R13	1.270	R32	1.198	R51	1.920
R14	0.793	R33	1.596	R52	1.649
R15	1.303	R34	1.243	R53	1.966
R16	0.838	R35	1.629	R54	1.694
R17	1.335	R36	1.289	R55	2.011
R18	0.883	R37	1.661	R56	1.739
R19	1.368	R38	1.334		

10.7 GHZ
CORRUGATED HORN
REVISION A

(CASE 40)

ALL CHOKE WIDTHS = 0.215
ALL LAND WIDTHS = 0.214

HORN INPUT FLANGE TO MATE
WITH ORTHOMODE TRANSDUCER

ALL INTERNAL CIRCLES
ROUND TO 0.001 TIR AND
CONCENTRIC TO 0.001 INCH
MANDREL TOLERANCES: 0.001

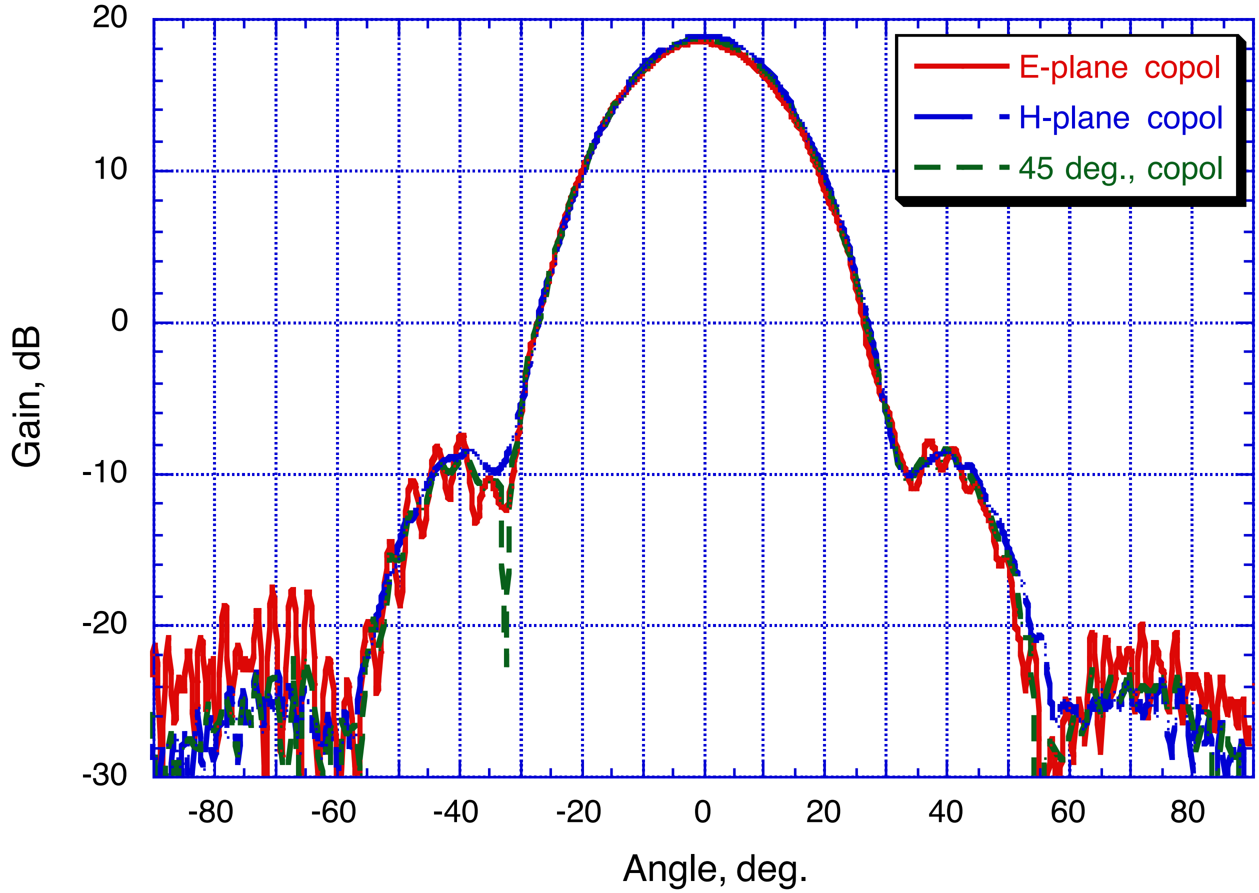
OTHER TOLERANCES
2 PLACES 0.010
3 PLANCE 0.005

NOT TO SCALE

Breadboard 10.7 GHz FeedHorn Anechoic Chamber Measurements

- Measurements Performed at NRL in Bldg. 68 Chamber (Reflected Energy < -45 dB)
- Data Is Used Both to Characterize Quality of Feed and As Input to Ohio State Reflector Code for POE Code Predictions

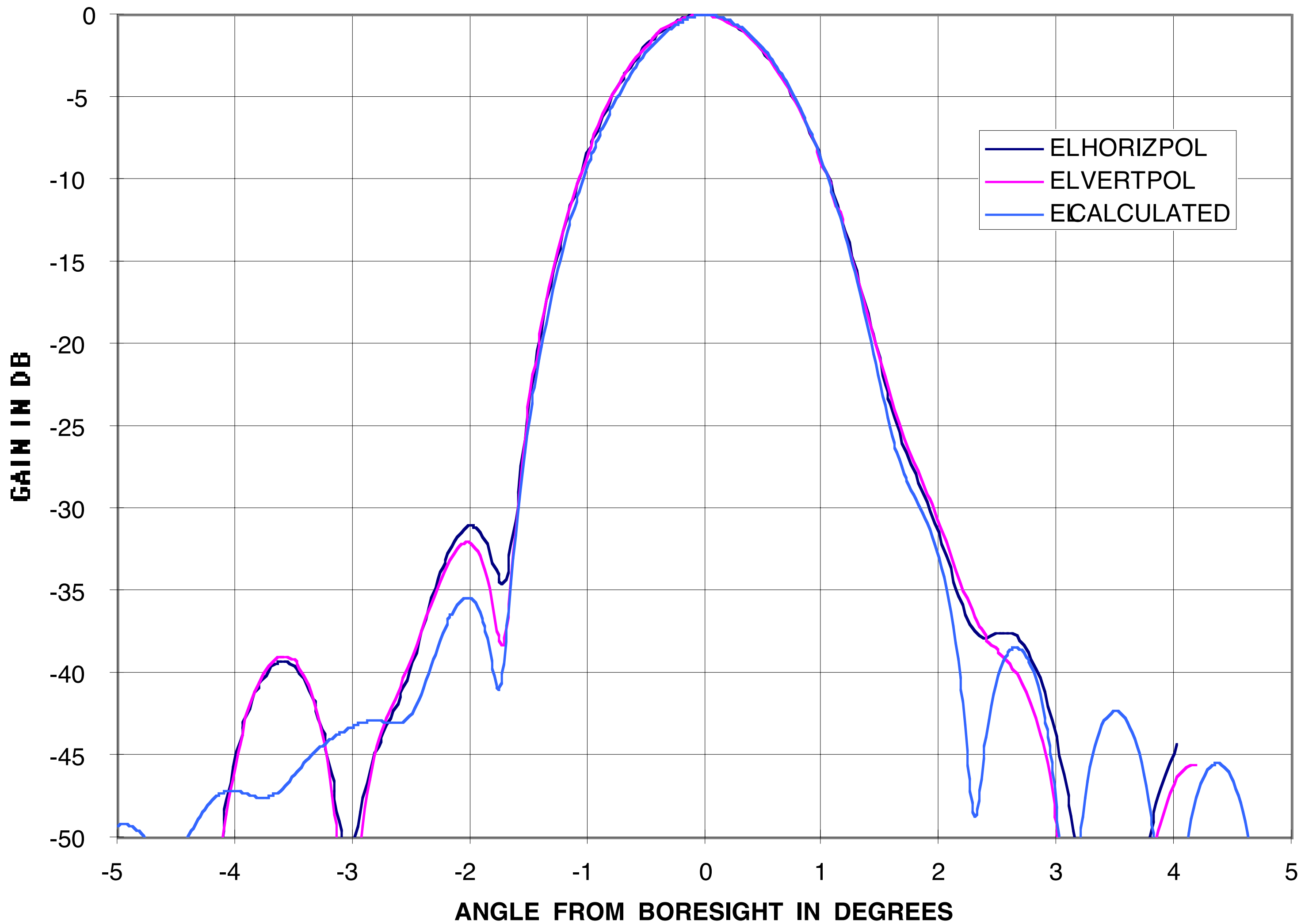
10.7 GHz FeedHorn Anechoic Chamber Gain Measurements



Port 1 Data, Showing Good Rotational Symmetry between the Planes

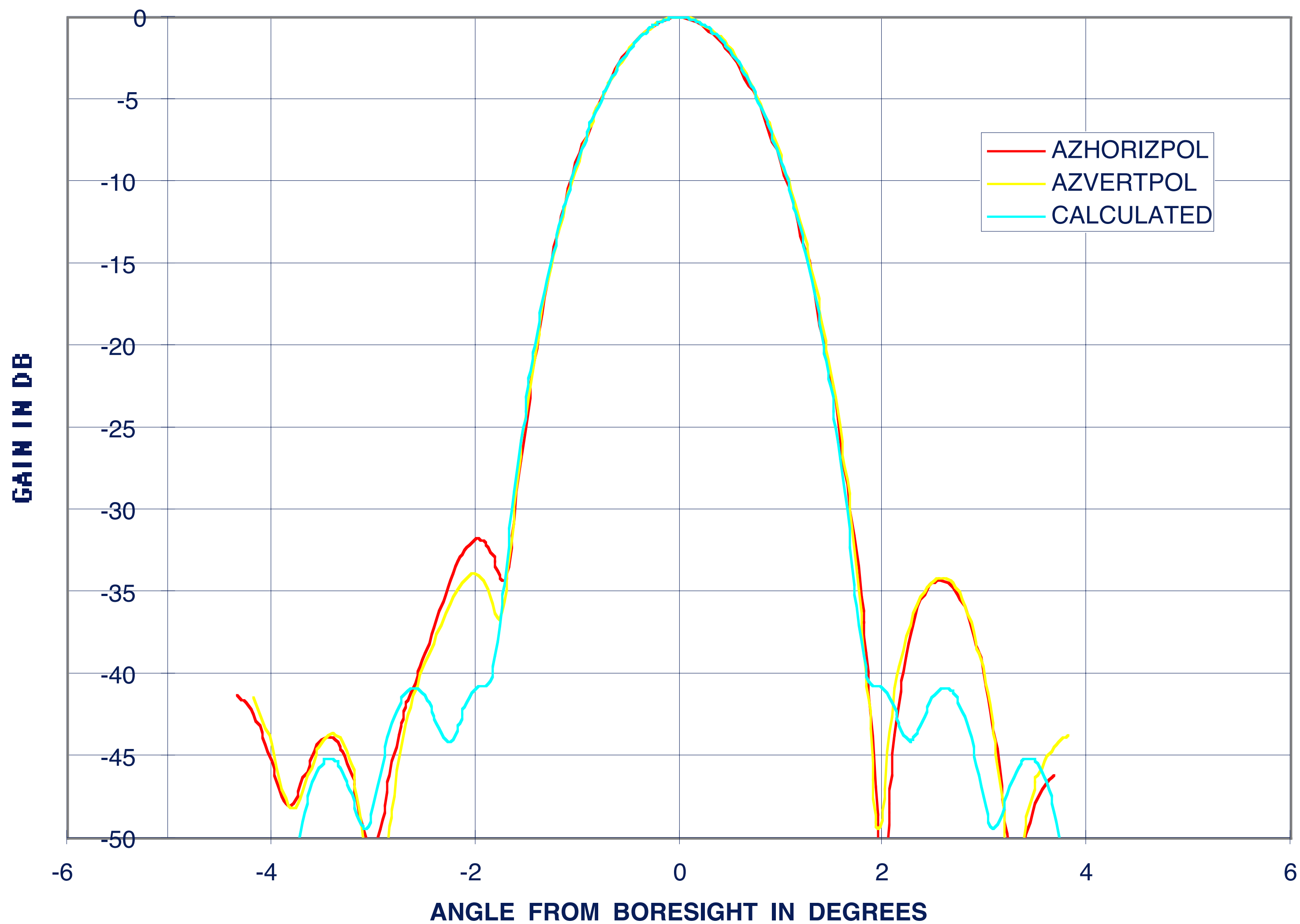
Breadboard Antenna

Measured vs. Calculated EL Patterns At 10.7 GHz



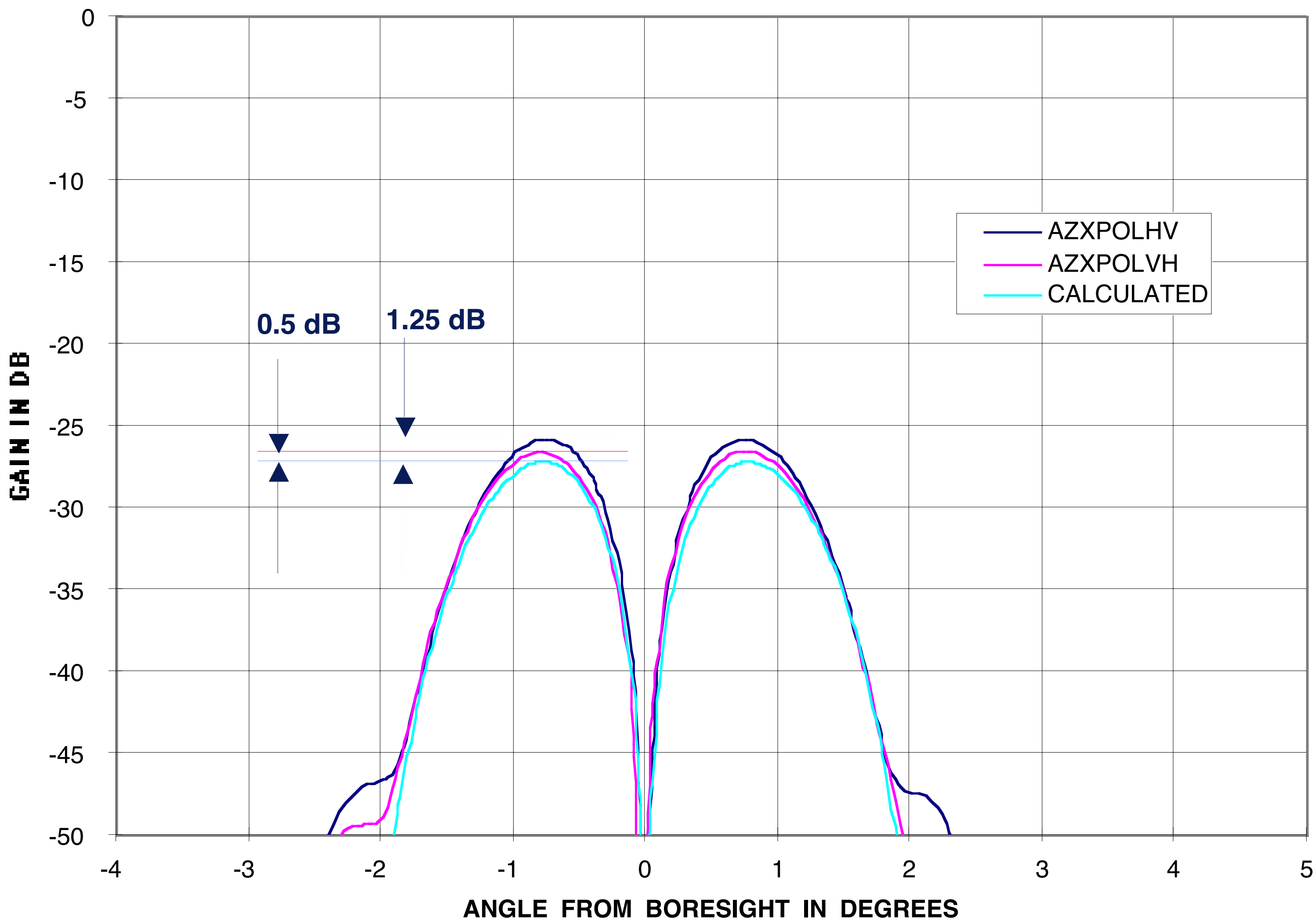
Breadboard Antenna

Measured vs. Calculated AZ Pattern At 10.7 GHz



Breadboard Antenna

Measured vs. Calculated AZ Crosspol Patterns At 10.7 GHz



Enhanced Breadboard Test Plans

- Use Existing Antenna Test Fixture
- Use Existing Data Acquisition System
- Procure New Reflector With Revised Geometry
- Procure Positioners With Shaft Encoders
- Use Existing 37 GHz And 10.7 GHz Breadboard Feeds
- Procure 1 Each Additional 37 GHz And 10.7 GHz Feeds For Coupling Measurements
- Build 7 Dummy Feeds For RF Environment Simulation

Antenna Integration and Alignment

Dick McBirney

Alignment Requirements - Performance

- WindSat Operation Is Critically Dependent on Controlling (to Close Limits) and Knowing (to Even Closer Limits) the EIA, SAA, and PRA
- The Alignment Share of These Limits Are As Low As ±0.005° per axis (=±18 arc sec). Controlling and Knowing These Angles on Orbit Will Require Measuring Inter-component Alignments During Several Program Phases:
  - Mechanical Assembly: Verify Static Angular Alignments
  - Design and Fabrication: Properly Place and Orient Optical Cubes
  - RF Range Testing: Measure and Record Final Alignments
  - Environmental Testing: Ensure That No Changes Occur

Alignment Requirements - Environmental

- **Alignments - Environmental Requirements**
  - **WindSat Functional Alignment Requirements Must Be Met:**
    - **After All Ground Testing Is Completed,**
    - **After Enduring Launch and Deploy Vibration, Then**
    - **Over the Operational Temperature Range**

- **Alignment Optical Cubes - Environmental Requirements**
  - **To Allow the Above Alignments to Be Measured and Verified, the WindSat Optical Alignment Cubes Must Maintain Their Angular Accuracy Relative to Their Associated Component Through All Ground Testing**

Alignment Requirements - Changes From SRR

- WindSat Angular Alignment Requirements Were Presented at SRR:
  - Part of Overall System Error Budget, and
  - Attitude Control System Requirements
- These Requirements Have Been Revised to Reflect Latest Design Configuration and Nomenclature

Trades Made - Reflector Roll Adjustment

- To Align Main Reflector Sidelobes, Reflector Should Be Rotated About Its RF Boresight (Option 1):
  - Pro: Rotates Sidelobes Directly
  - Con: Very Difficult to Implement, Offsets Focal Point
- Alternates Are to Rotate About Feedhorn LOS (Option 2) or Rotate About Dish Normal (Option 3) :
- Consider Option 2: Rotate About Feedhorn LOS
  - Pro: No Focal Point Offset
  - Con: Very Difficult to Implement
- Consider Option 3: Rotate About Dish Normal
  - Pro: Easy to Implement, Will Be Tested on Antenna Breadboard
  - Con: Smaller Focal Point Offset Than (1)
- We Chose Option 3: Dish Normal Rotation:
  - Meets RF Requirements
  - Easy to Implement
  - Breadboard Test Data Will Demonstrate It Works

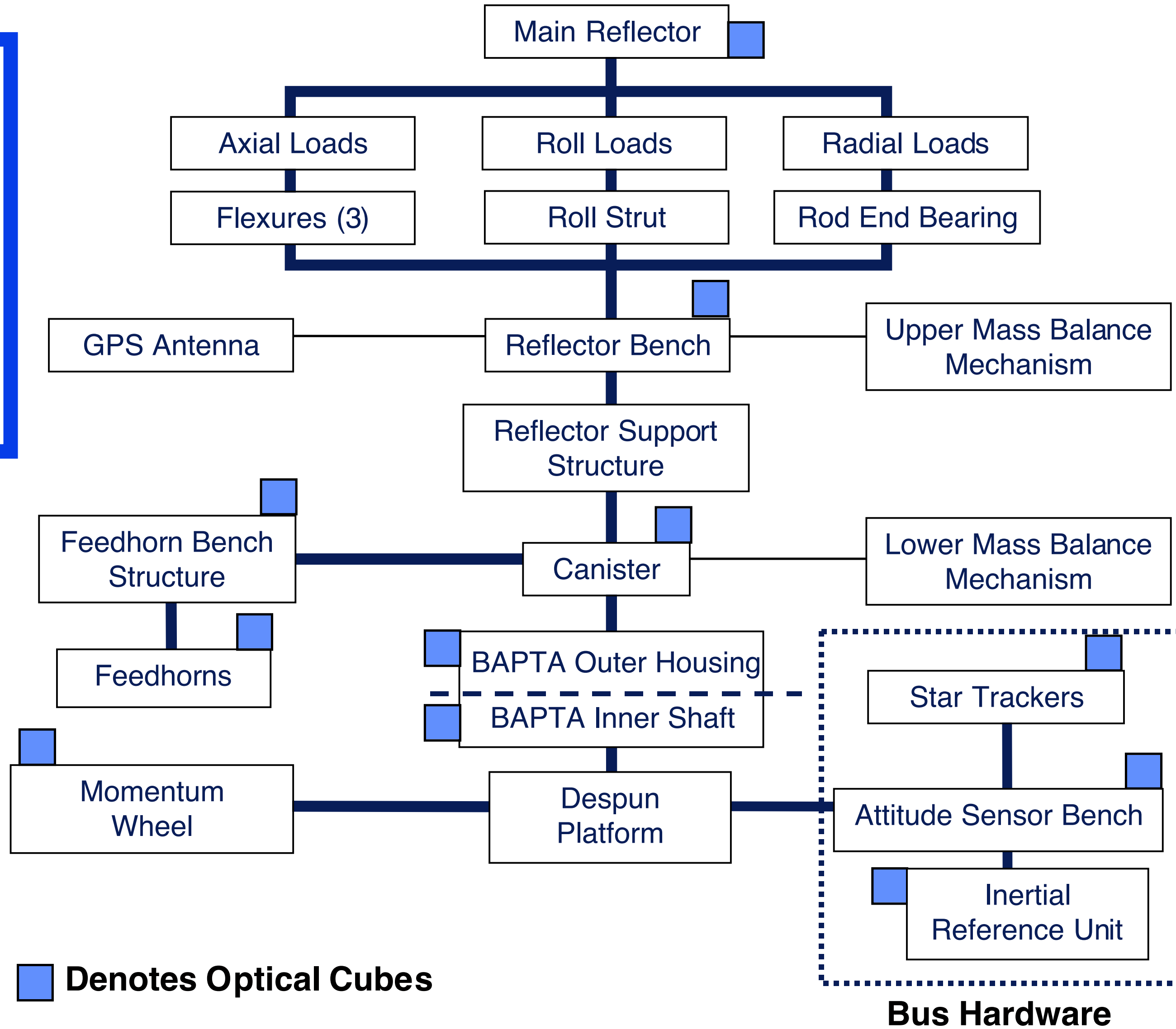
Alignment Technique uses Optical Tooling

- To Measure Angular Alignments of the Antenna, We Will Use:
  - Optical Cubes
    - Attached at Strategic Points on RF and Mechanical Components
    - Redundant Cubes Used at All Locations
  - Optical Tooling:
    - Rotary Table
    - Theodolite
    - Vertical Tooling Bar

- Optical Metrology Selected Because Its 3σ Accuracy of ±10 ArcSec Meets Our Tightest Requirement of ±18 ArcSec (=±0.005 Degrees)

Structural Diagram

To Determine Required Cube Locations, Consider This Structural Diagram of the WindSat Payload



Heavy Bars on Structural Diagram Are Structural Paths Between Alignment-Critical Components

There Are Three Requirements on Each Cube:

- Each Cube Must:

  1. Be Located on Critical WindSat Components Near Their Alignment Critical Features,

  2. Be Accurately Oriented Relative to the Relevant Axes of Those Components, and

  3. Be Visible to the Theodolite

- Cube Locations, Alignments, Visibility Will Be Validated on Mockup Prior to CDR

- The Following Slides Detail How We Will Meet These Three Requirements

(1) Optical Cubes Must Be Located at Critical Points

- **Main Reflector:**
  - On the Back of the Dish, Near the Dish Center (Low Deflection, Most Critical RF Area)
- **Reflector Bench**
  - On the Bench Side Nearest the Dish
  - Near the Dish Center
- **Canister**
  - On Canister Structure That Is Near Spin Axis.
- **BAPTA**
  - On BAPTA Inner and Outer Housings
- **Feedhorns**
  - Near Feedhorn Component That Determines Its Polarization Plane.
- **Feedhorn Bench**
  - Near Structurally Rigid Portion of Feed Bench That Determines Feedhorn Locations.
- **Attitude Sensor Bench**
  - [TBD]
- **Inertial Reference Unit (IRU)**
  - [TBD]
- **Star Trackers**
  - [TBD]
- **Momentum Wheel**
  - [TBD]

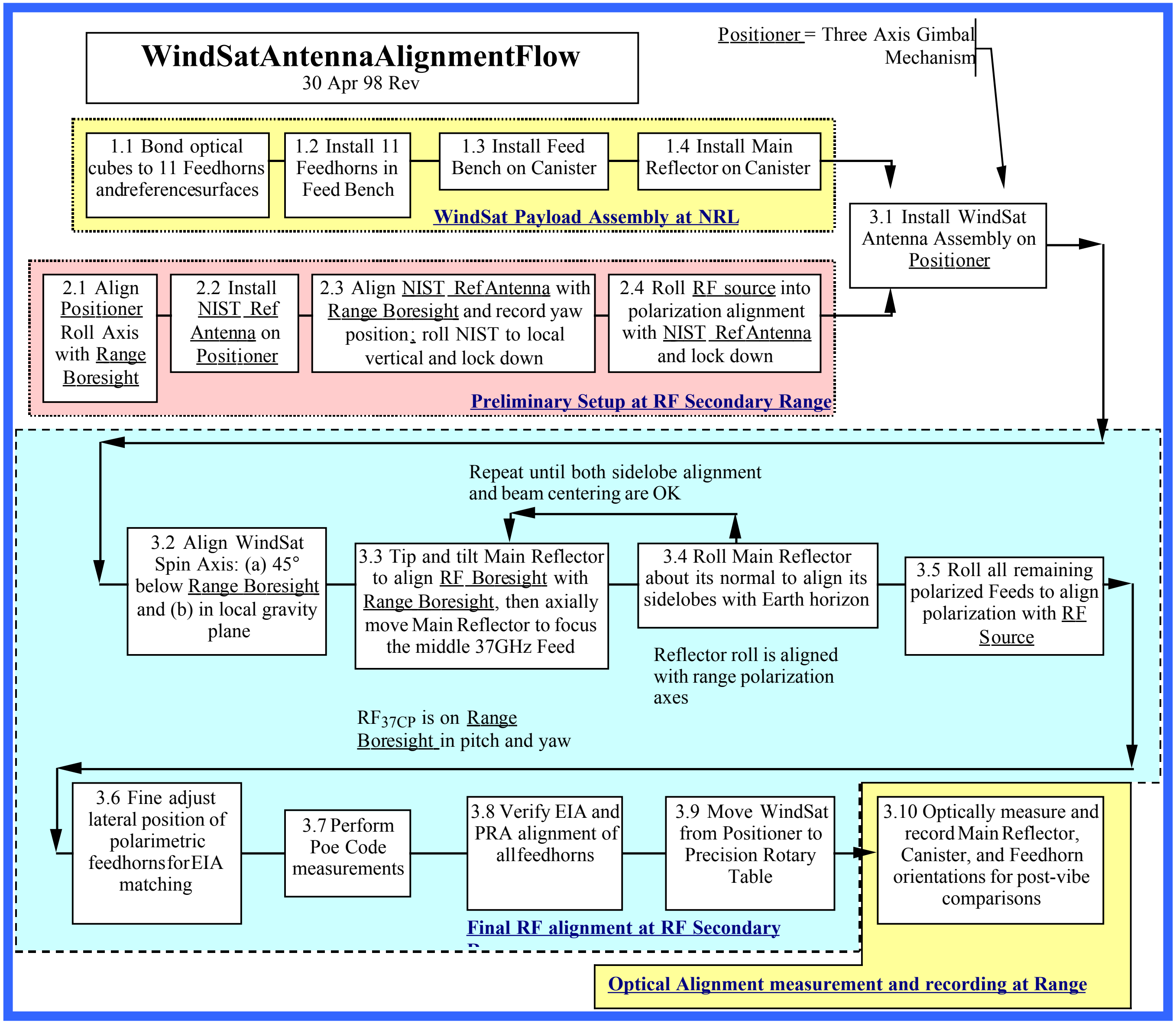
(2) Optical Cubes Faces Must Be Precisely Oriented Relative to Critical Coordinate Axes

- **Main Reflector:**
  - The "Virtual Line" of a Cube (the Normal to Two Adjacent Cube Surface Normals) Will Be Aligned to an Easily Measured Feature of the Dish (I.E., The "Cookie Cutter" Line or the "Dish Normal" Line). This Feature Must Be Easily Related in 3D Space to a Functional Line, Such As the RF Boresight
- **Reflector Bench**
  - The Virtual Line Will Be Aligned to an Easily Measured Feature of the Reflector Bench (I.E., Normal to One Side of It)
- **Canister**
  - The Virtual Line Will Be Aligned to the Canister Spin Axis. One Face Is Aligned to SAA = 0°
- **BAPTA**
  - The Virtual Line Will Be Aligned to the Canister Spin Axis. One Face Is Aligned to SAA = 0°
- **Feedhorns**
  - The Virtual Line Will Be Aligned to the Longitudinal Axis of the Feedhorn
  - The Normal to Each of the Optical Cube Surfaces Will Be Parallel to a Polarization Plane of the Feedhorn, Unless Visibility Considerations Render This Orientation Impossible
- **Feedhorn Bench**
  - The Virtual Line Will Be Aligned to the RF Boresight Between the Center 37 GHz Feedhorn and the Main Reflector
- **Attitude Sensor Bench**
  - The Virtual Line Will Be Aligned to [TBD]
- **Inertial Reference Unit (IRU)**
  - The Virtual Line Will Be Aligned to [TBD]
- **Star Trackers**
  - The Virtual Line Will Be Aligned to [TBD]
- **Momentum Wheel**
  - The Virtual Line Will Be Aligned to [TBD]

(3) Optical Cube Faces Must Be Visible to the Theodolite

- **Main Reflector**
  - Normals (to Each of the Optical Cube Surfaces) Visible Through Gap Between Dish and Reflector Bench
- **Reflector Bench**
  - Normals Visible Through Gap Between Dish and Reflector Bench
- **Canister**
  - Normals Visible From Outside Canister When All Functional Components and Structural Panels Are Installed. Nonstructural Covers May Be Removed
- **BAPTA**
  - Normals Visible From Outside Canister When All Functional Components and Structural Panels Are Installed. Nonstructural Covers May Be Removed
- **Feedhorns**
  - Where Necessary, Normals Can Be Rotated Away From a Parallel to a Polarization Plane of the Feedhorn, to Be Visible From Outside Canister. It Is Desirable to Keep This Rotation to Even Values (I.E., Precise Multiples of 10°). Nevertheless, Virtual Line Will Still Be Aligned to Longitudinal Axis of Feedhorn
- **Feedhorn Bench**
  - Normals Visible From Outside Canister. Nonstructural Panels May Be Removed
- **Attitude Sensor Bench**
  - Normals Visible From Outside Canister. Nonstructural Panels May Be Removed
- **Inertial Reference Unit (IRU)**
  - Normals Visible From Outside Canister. Nonstructural Panels May Be Removed
- **Star Trackers**
  - Normals Visible From Outside Canister. Nonstructural Panels May Be Removed
- **Momentum Wheel**
  - Normals Visible From Outside Canister. Nonstructural Panels May Be Removed

Alignment Flow Diagram



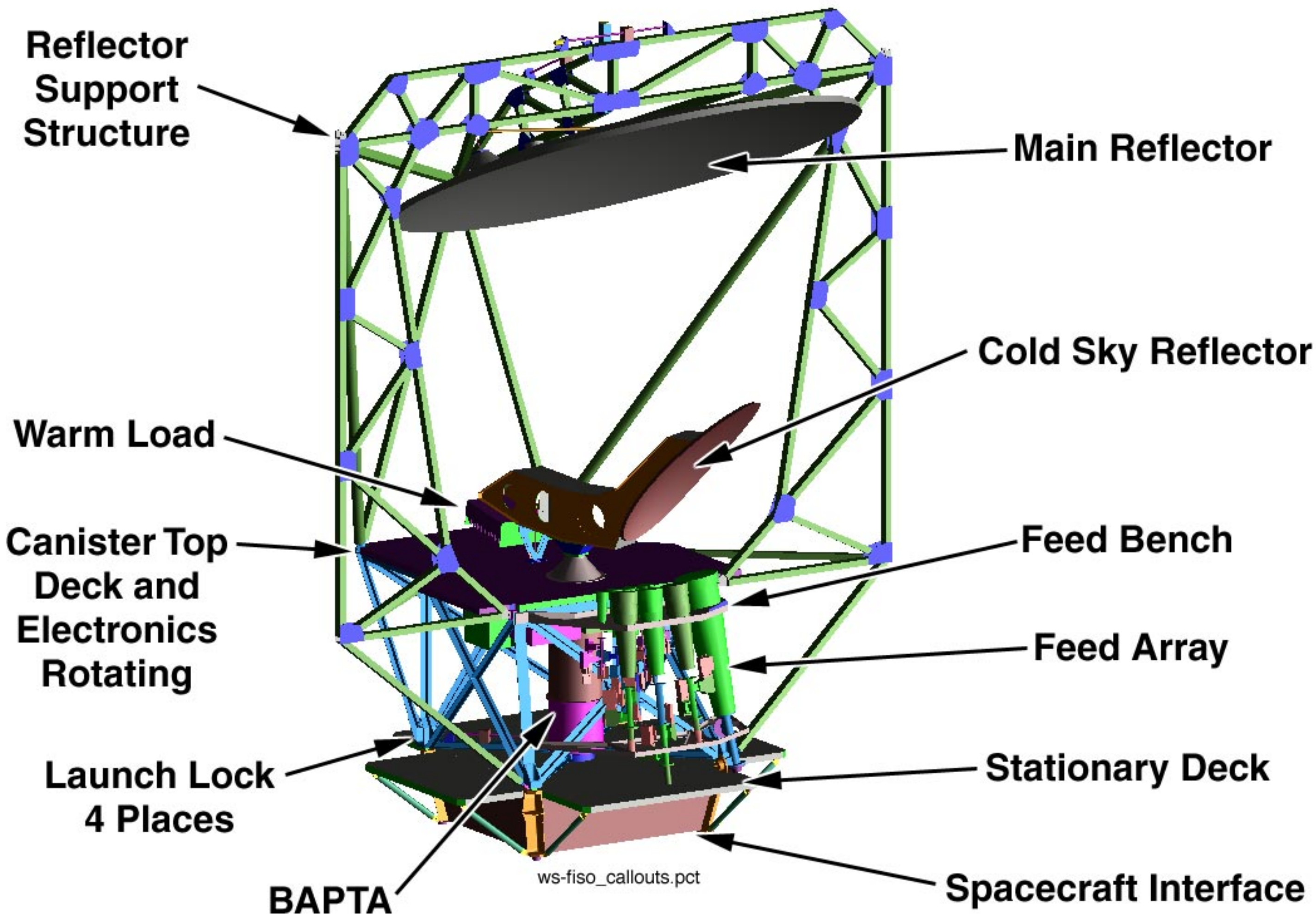
Capabilities vs. Requirements

- Tightest Alignment Measurement Requirement Is ±0.005°, or ±18 Arc Sec
- Optical Tooling Is Much More Accurate:
  - Optical Cubes Are Square to ±2 Arc Sec
  - Cube Mounting is Stable to ±2 Arc Sec
  - Autocollimating Theodolite and Rotary Table Read to ±1 Arc Sec, Are Accurate to ±2 Arc Sec
- Optical Tooling Tolerances Are Much Smaller Than Measurement Requirements, So WindSat Angular Alignments Can Readily Be Held With Optical Techniques

On-Orbit Calibration Loads

P. Gaiser

WindSat Concept Definition



Derived Calibration System Requirements

	Bias, K	Random, K	C/I *	Predicted, K
Warm Load				
Emissivity	-0.15		C, I	-0.07
Measurement Accuracy		± 0.1	C	± 0.06
Temperature Drift		± 0.05	C	± 0.05
Gradient		± 0.1	C	± 0.10
Warm Total	**-0.15**	**± 0.15**		**-0.07 ± 0.13**
Cold Load				
Cosmic Uncertainty		± 0.02	C	± 0.02
Earth Sidelobes	+0.25	± 0.14	C,I	+ 0.09 ± 0.06
Spacecraft Sidelobes	+0.15		C,I	+ 0.10
Cold Total	**+0.40**	**± 0.15**		**+ 0.19 ± 0.063**

* C/I - Common mode or Independent

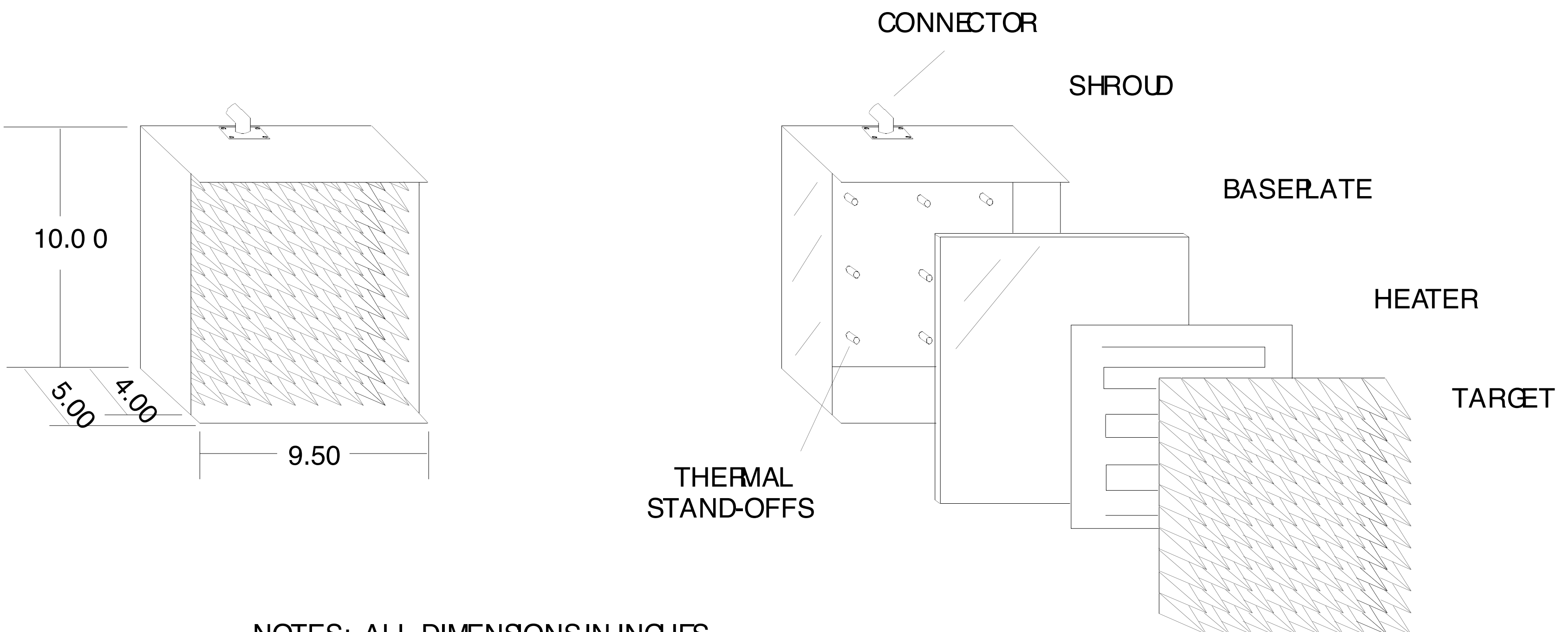
Trade Studies

- Warm Load
  - Square-based Pyramidal Load Vs. Conical Load
    - Polarization Sensitivity Due to Linear Structure of Warm Load
    - Emissivity Variation With Geometry During Warm Load Calibration Part of Scan
- Cold Sky Reflector Optimization
  - Minimize Scan Occlusion by Varying Following Parameters
    - Feed Array Offset From Spin Axis
    - Offset of Primary Reflector
    - Pointing Angle of Cold Reflector Main Beam Relative to Spacecraft Horizontal
    - Focal Length of Cold Sky Reflector
  - Must Preserve Satisfactory Performance of Cold Sky Reflector As Antenna and Calibration Source
  - Minimum Number of Two Samples at 6.8 GHz Per Scan

Warm Load Design Baseline

- Radiometric Absorber Remains Stationary As Feed Horns Pass Under Every Scan
- Warm Load Basic Design Parameters
  - Square-based Pyramids With 0.75 Inch Base and 4:1 Height to Base Ratio
  - Eccosorb CR-117 Epoxy Coating on Aluminum Core
  - 9.5 by 9.0 Inches
    - Ensures Excellent Coupling of Entire Feed Horn Array and Minimum of Four Calibration Samples at 6.8 GHz
    - Maximum Scan Occlusion of 75°
  - Low Power Heater to Ensure Minimum Temperature (250K)
    - Heater Is Not Thermostatically Controlled
  - Six Platinum Resistance Thermometers (PRT) Distributed Across Load
- Warm Load Surrounded by Shroud to Improve Coupling and to Minimize Thermal Gradients
- Interfaces - Mechanical, PRT's, Heater

Warm Load System



NOTES: ALL DIMENSIONS IN INCHES

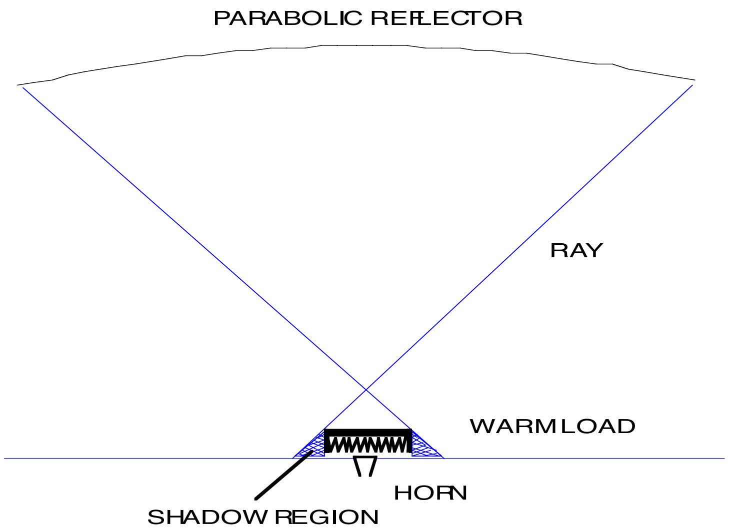
WEIGHT: 12 LBS.

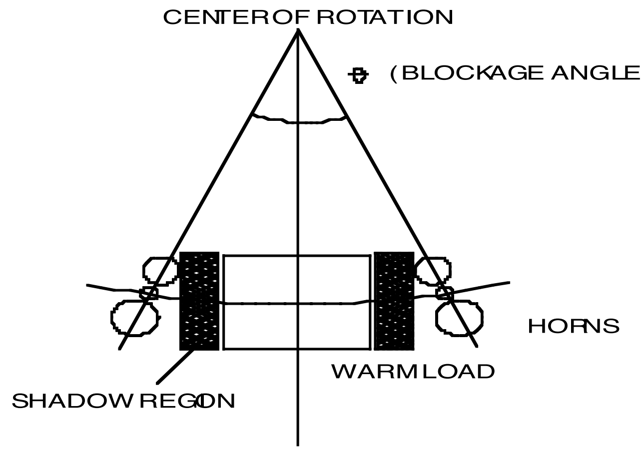
HEATER-KAPTON, 5W

CONNECTOR (MIL-C-38 999)

PYRAMIDS: 3" :0.75 " (HEIGHT:BASE 4:1)

Warm Load Blockage

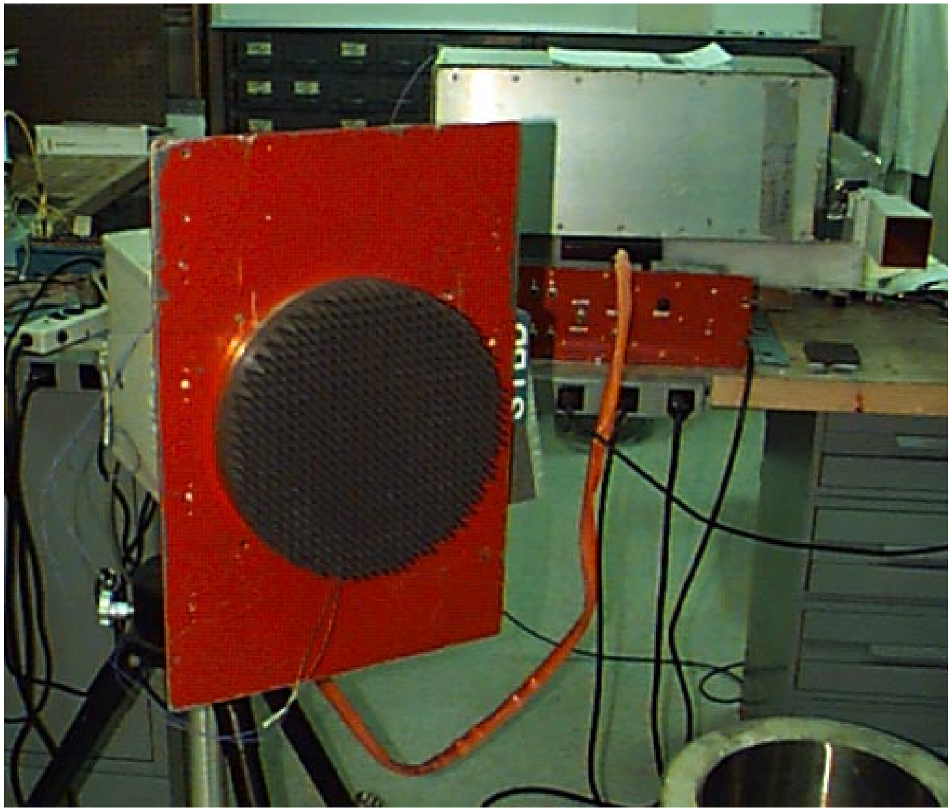




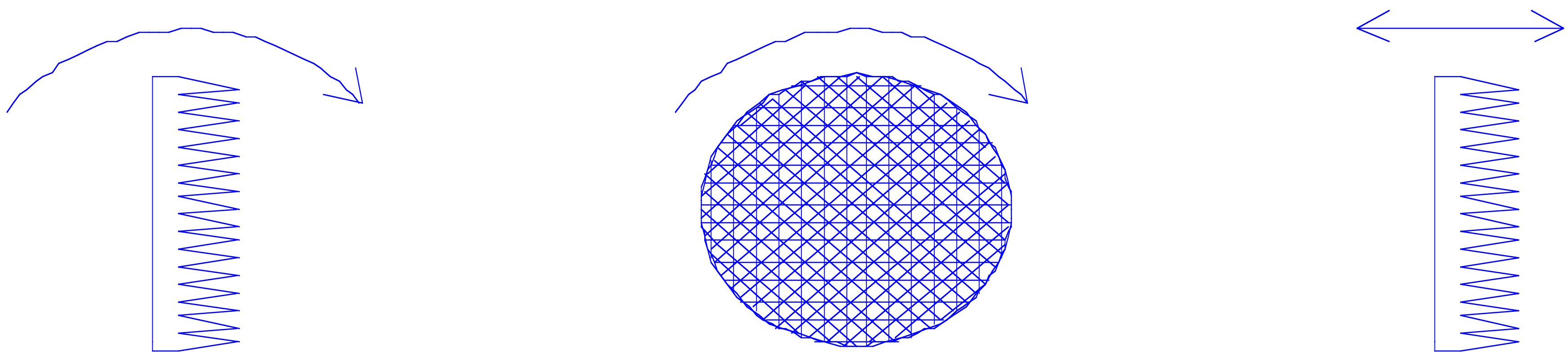
Frequency GHz	Horn to Center Spin Axis (Radius in Inches)	Circumference (Inches)	Horn Diameter (od) (Inches)	Arc Length Blocked (Inches)	Blockage Angle (Degrees)	Block/Revolution (%)
6.8	18	113.10	6.2	23.82	75.82	21.06
10.7	20.9	131.32	4.0	20.76	56.92	15.81
18.7	15.9	99.90	2.3	19.40	69.91	19.42
23.8	18	113.10	1.9	18.64	59.34	16.48
37	18	113.10	1.2	17.84	56.79	15.78

Warm Load Prototype

- Prototype
  - Aluminum Core Coated With CRS-124 Silicone Resin, Manufactured by Zax Millimeter. This Resin Can Be Repeatedly Cycled to Liquid Nitrogen Temperatures
  - 4:1 Ratio of Base to Height for Pyramids
  - 25 Watt Kapton Heater for Temperature Variation
  - 3 PRT Monitoring Points



Warm Load Prototype Testing

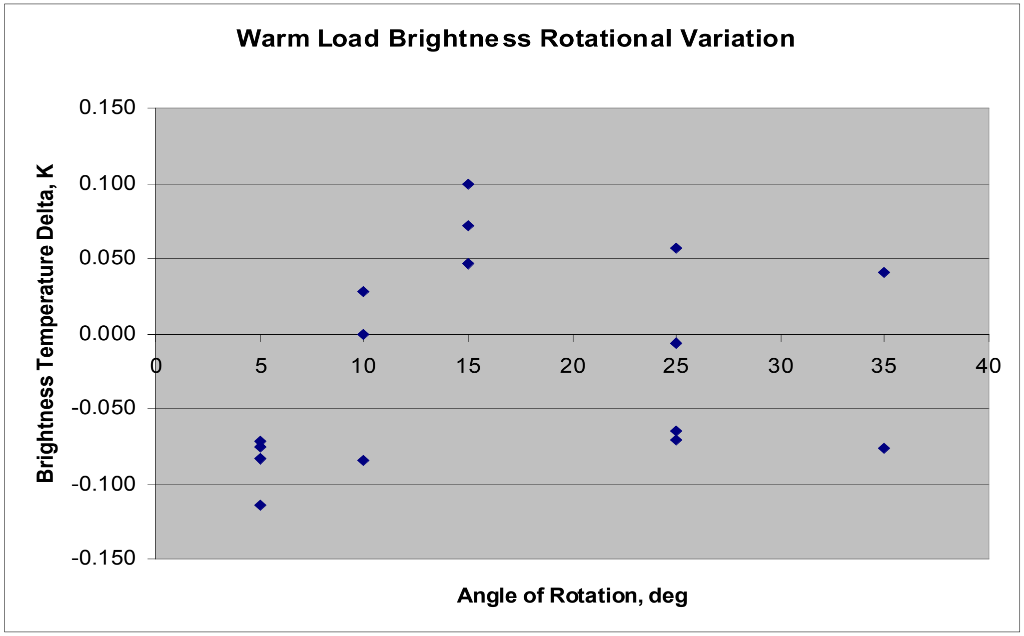


Configuration 1 Configuration 2 Configuration 3

- Configuration 1: Emissivity Variation with Incidence Angle
- Configuration 2: Emissivity Variation with Warm Load Rotation (Polarization Sensitivity)
- Configuration 3: Optimal Coupling and Test for Presence of Standing-Waves

Warm Load Breadboard Test Results

- Emissivity Is Stable for Given Incidence Angle; Each Incidence Angle Must Be Calibrated
- No Standing Wave Behavior Detected; None Expected Because of Direct Detection Design and Front End Isolators
- Testing at 37 GHz Indicates Negligible Variation With Rotational Angle
  - Variation Lies Within Required Accuracy of Warm Load Emissivity



Warmload_plot.xls

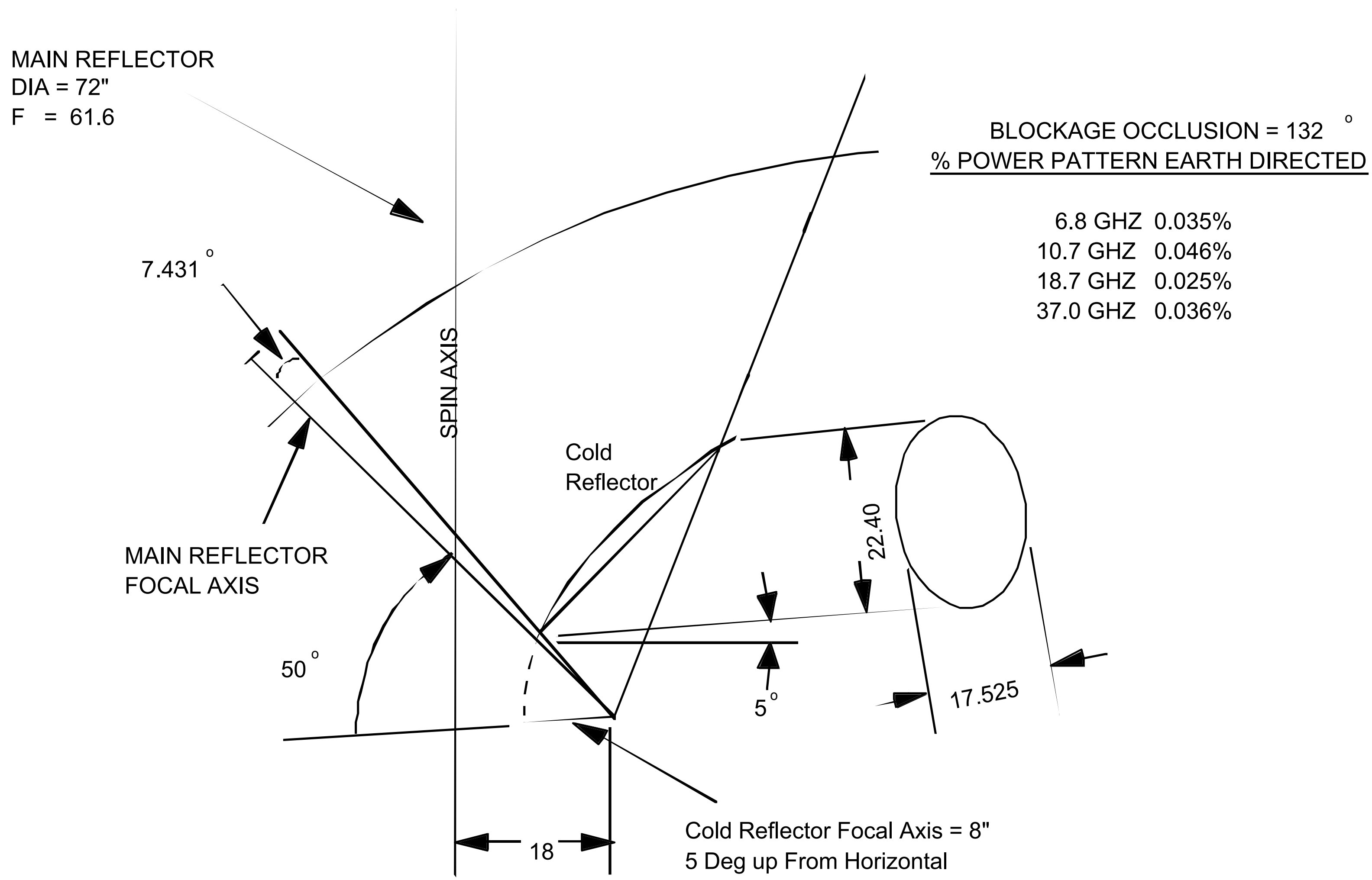
Cold Sky Reflector Derived Requirements

- < 0.39 K of Received Energy from Earth(< 0.13 % of integrated beam energy)
- < 0.15 K of Received Energy from Spacecraft
- Reflector Sized and Positioned to Minimize Scan Occlusion While Providing to Minimum Needed Calibration Samples at 6.8 GHz
- Completely Block Feed View of Main Reflector Once per Scan

Cold Sky Reflector Design Baseline

- Offset Parabolic Reflector Remains Stationary As Feed Horns Pass Below Every Scan
  - 17.525 X 22.40 Inch Elliptical Reflector
  - Completely Blocks Feed Horn View of Primary Reflector
  - Large Enough to Provide Two Cal Samples at 6.8 GHz Per Scan
  - Focal Length of 8 Inches (f/D = 0.141)
  - Main Beam Pointed 5° up From Spacecraft Horizontal
- Reflector Surface Is VDA (Vapor Deposited Aluminum) – Same As Main Reflector
- 5 mil RMS Manufacturing Surface Tolerance
- Results in Scan Occlusion of 132°
- Interfaces
  - Mechanical
  - Thermistor

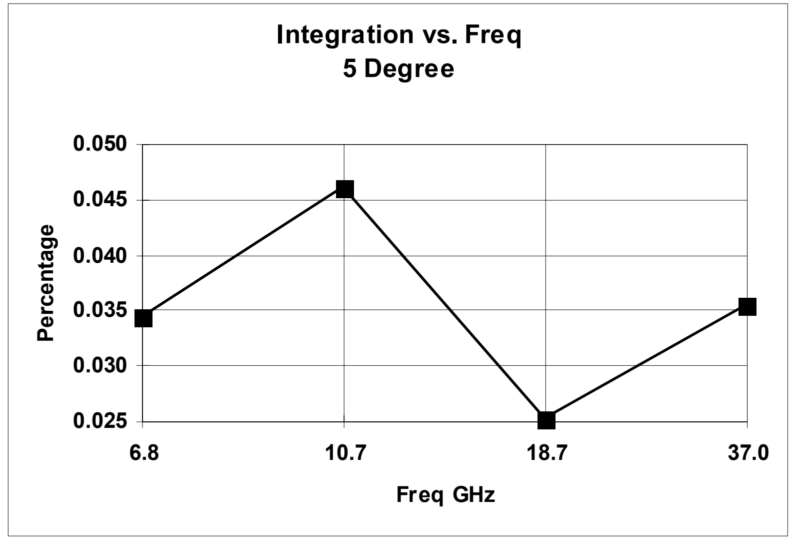
Cold Sky Reflector Drawing



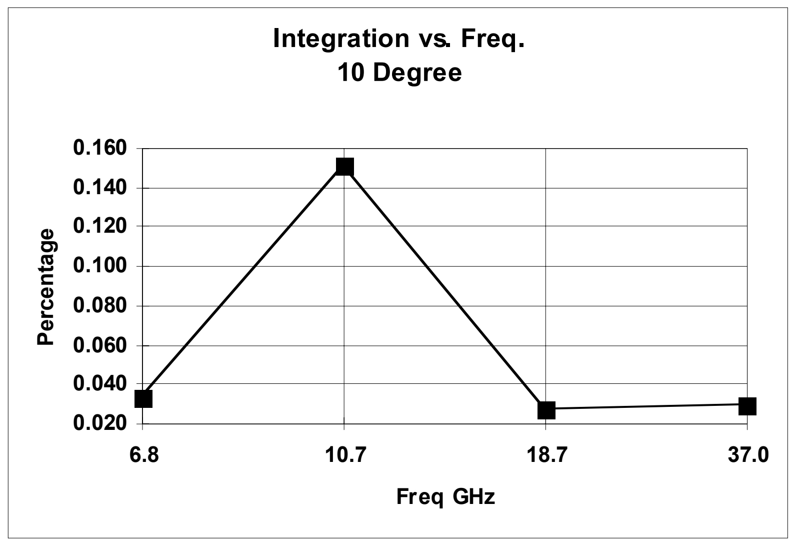
Earth Intercept Integration

Beam intercepts Earth 27° below S/C horizontal

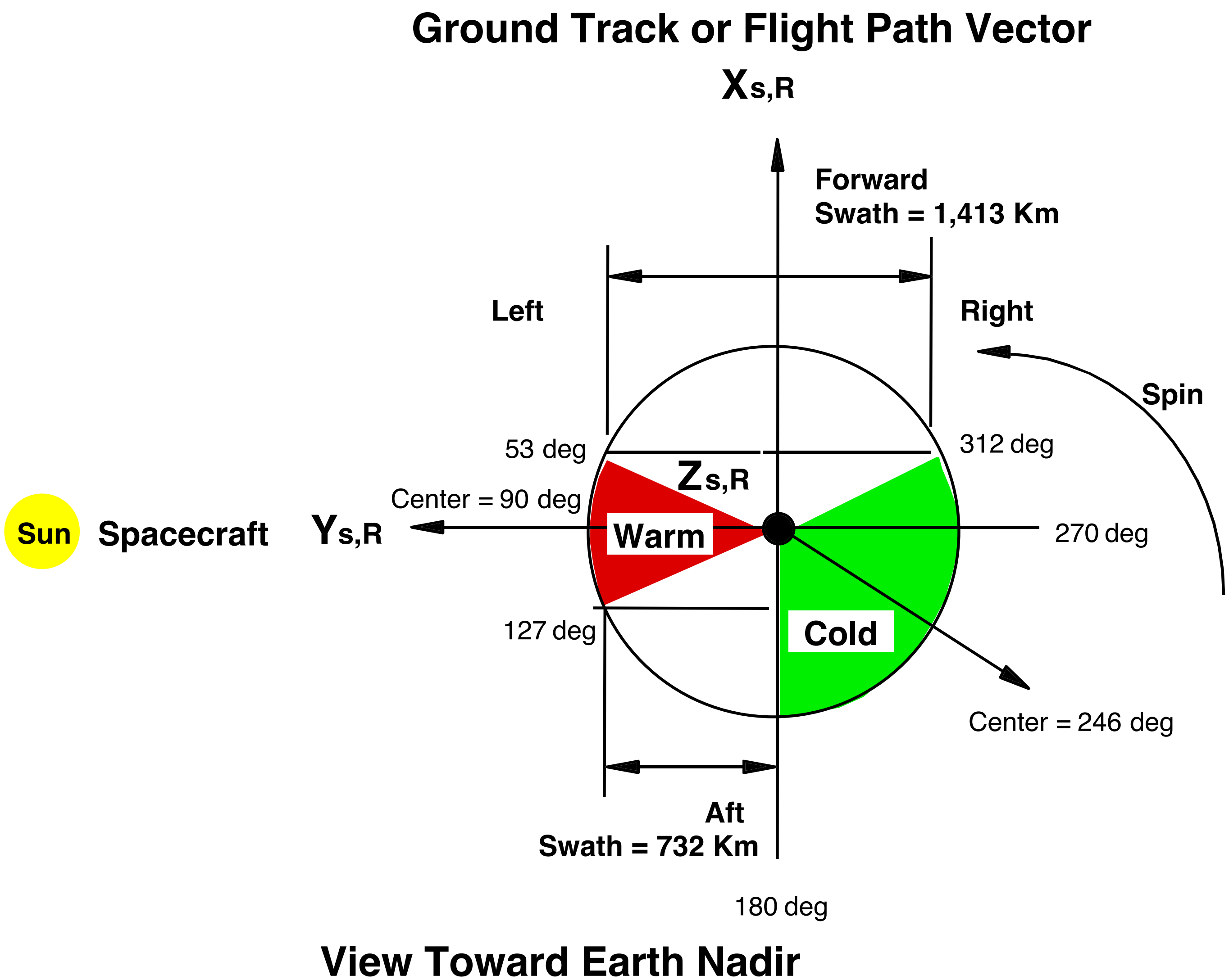
5 Degree Raised Beam				
Freq(GHz)	Total	<-27 Deg	Integration	Percentage
6.8	14.94636	0.00514	0.00034	0.03439
10.7	6.57130	0.00302	0.00046	0.04603
18.7	3.80471	0.00096	0.00025	0.02514
37.0	0.33281	0.00012	0.00036	0.03551



10 Degree Raised Beam				
Freq(GHz)	Total	<-27 Deg	Integration	Percentage
6.8	17.61057	0.00582	0.00033	0.03304
10.7	6.72092	0.01017	0.00151	0.15137
18.7	4.17441	0.00114	0.00027	0.02730
37.0	0.36776	0.00011	0.00029	0.02893



Resultant Swath Geometry



Implementation Plan

- Procurement
  - Warm Load
    - Purchase Flight Unit From Vendor
    - Approximately 6 Month Lead Time
  - Cold Sky Reflector
    - Purchase Flight Unit From Vendor
    - May Be Included in Procurement of Main Reflector

- Test Plan
  - Warm Load
    - Characterize Performance Using High Precision Differential Radiometer Testing in Flight Geometry
  - Cold Sky Reflector
    - Measure Antenna Pattern in Flight Configuration
    - Verify Reflector Emissivity

WindSat Power Conditioning

Bill Connoly

General Power Supply Requirements

- Three Types Of Power Converters Provide All Receiver, Data Handling System (DHS), And Momentum Wheel Assembly Needs
  - DEU Power Supplies: 5 Total, Two 2-Channel And Three 6-Channel
  - DHS Power Supplies: Two 1-Stationary (SDHU) And 1 Rotating (RDHU)
  - MWA Power Supply
- Input Characteristics: 28 ±6VDC
- EMC: MIL-STD 461, CS01, CS02, CS06, CE-01, CE-03, RE02
- Inrush Limiting On All Power Supplies

Detector Electronics Power Converter Output Requirements

6 Channel

	Output Voltage							
Output Voltage	5.0V	6.0V	-6.0V	12.0V	-12.0V	8.0V	9.0V	21.0V
Tolerance	5%	10%	10%	5%	5%	3%	5%	10%
Output Ripple Voltage	50mVp-p	25mVp-p	25mVp-p	25mVp-p	25mVp-p	100mVp-p	100mVp-p	100mVp-p
Output Current	0.12A	0.45A	0.45A	0.39A	0.39A	1.5A	0.62A	0.03A
Output Power	0.6W	2.7W	2.7W	4.7W	4.7W	12.0W	5.5W	0.6W
Where Used	Audio.Dig	Audio	Audio	Audio/Dig	Audio/Dig	RFA	LNA	LNA

Total Output Power: 33.61W

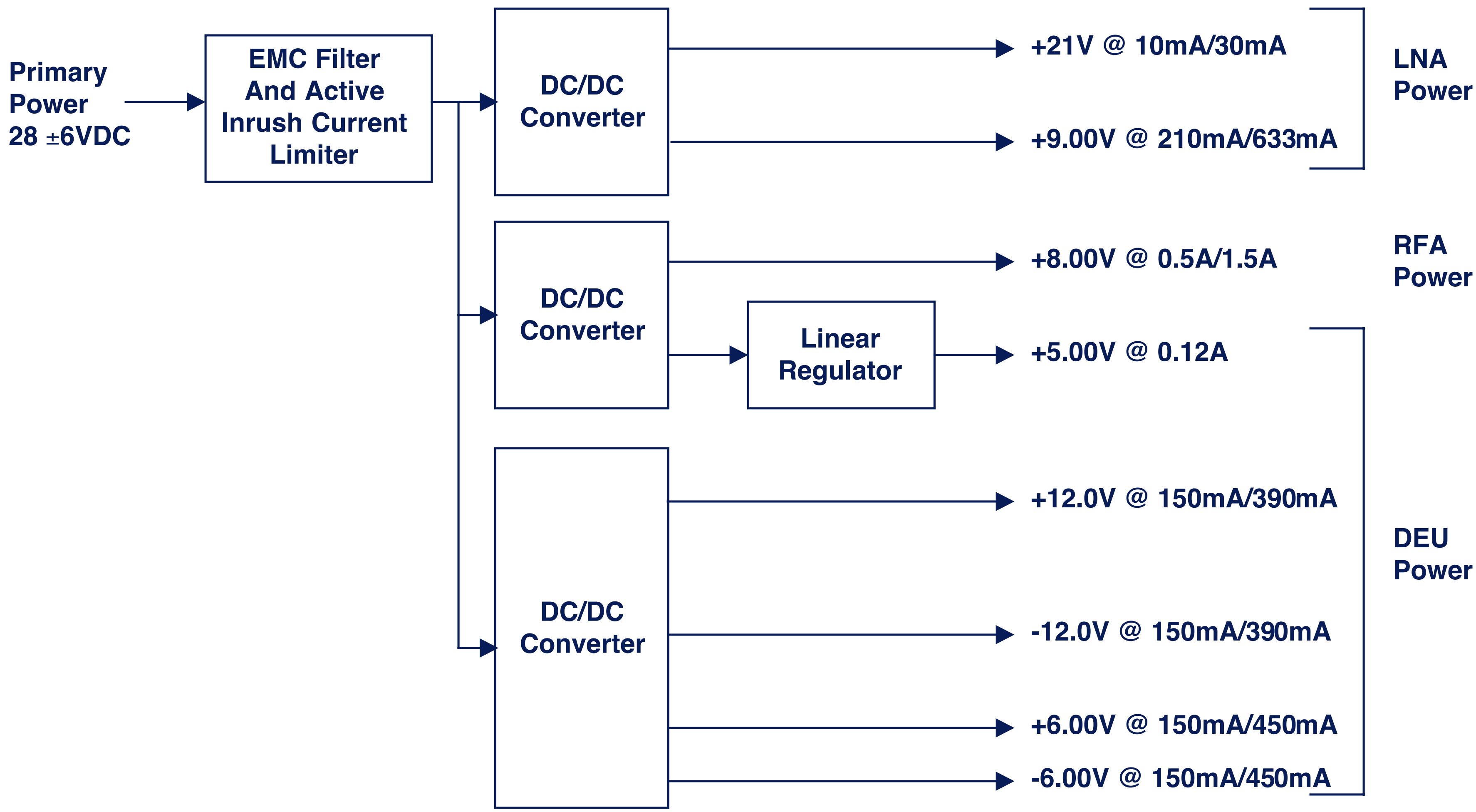
2 Channel

	Output Voltage							
Output Voltage	5.0V	6.0V	-6.0V	12.0V	-12.0V	8.0V	9.0V	21.0V
Tolerance	5%	10%	10%	5%	5%	3%	5%	10%
Output Ripple Voltage	50mVp-p	25mVp-p	25mVp-p	25mVp-p	25mVp-p	100mVp-p	100mVp-p	100mVp-p
Output Current	0.12A	0.15A	0.15A	0.15A	0.15A	0.60A	0.25A	0.01A
Output Power	0.6W	0.9W	0.9W	1.8W	1.8W	4.8W	2.3W	0.2W
Where Used	Audio/Dig	Audio	Audio	Audio/Dig	Audio/Dig	RFA	LNA	LNA

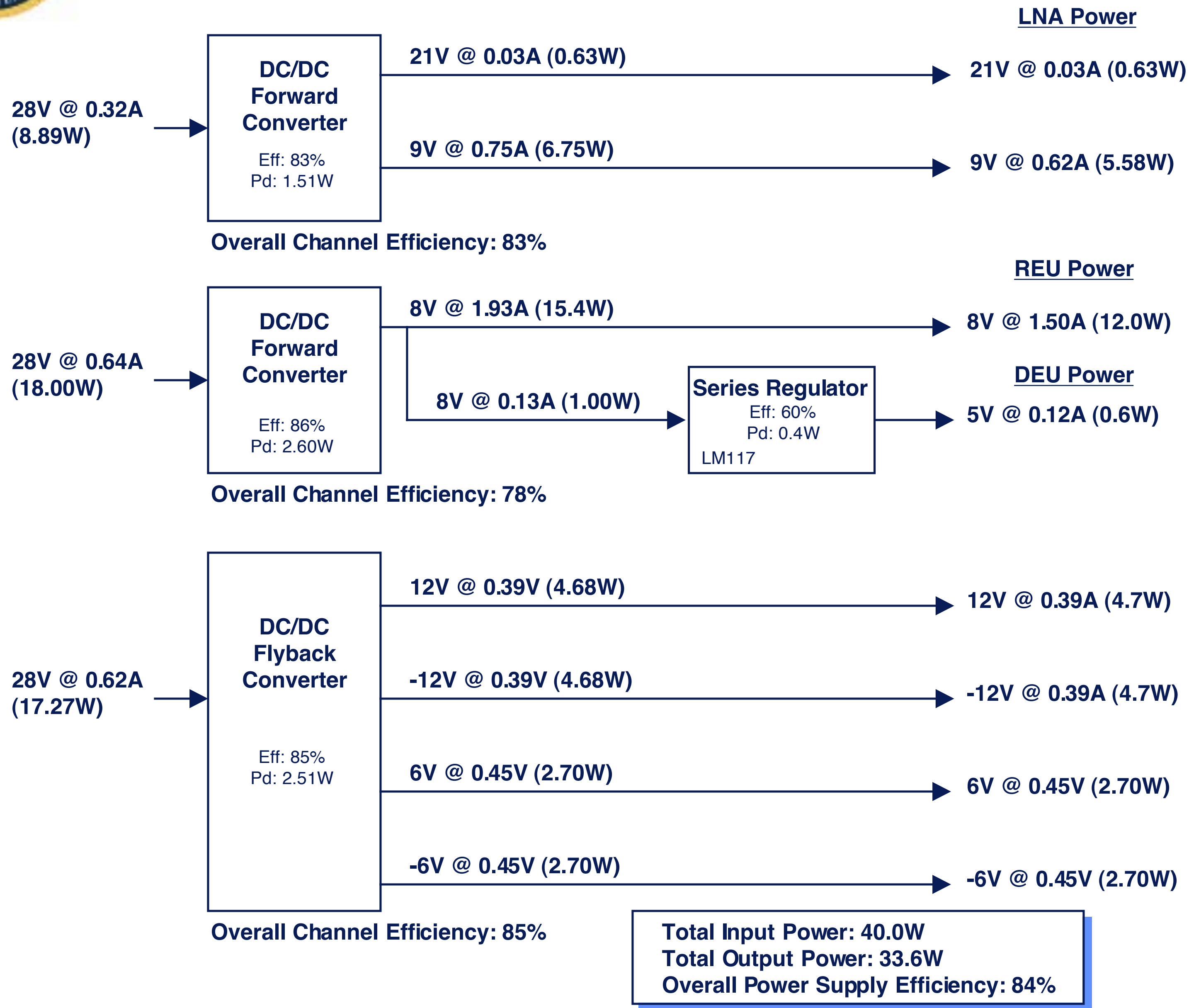
Total Output Power: 13.3W

Total DEU Output Power: 137.9W (Two 2-Channel Plus Three - 6-Channel Units)

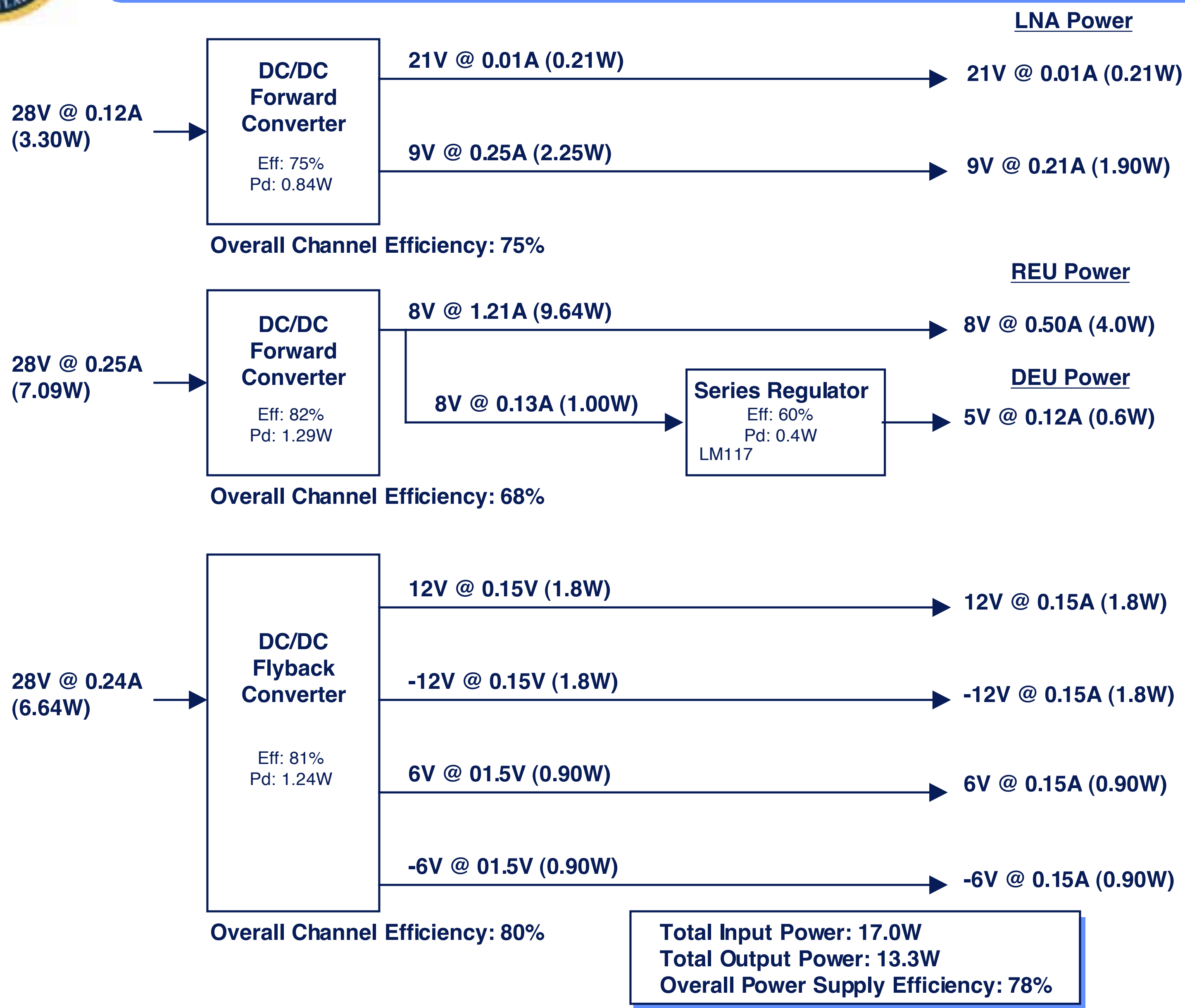
DEU Power Supply Block Diagram



DEU Power Supply (6-Channel)
Power Budget Diagram



DEU Power Supply (2-Channel) Power Budget Diagram



Power Converter Output Requirements

SDHU Power Converter Output Requirements

	Output Voltage			
Output Voltage	5.0V	-5.0V	15.0V	-15.0V
Tolerance	5%	5%	5%	5%
Output Ripple Voltage	50mVp-p	50mVp-p	50mVp-p	50mVp-p
Output Current	6.24A	1.70A	0.35A	0.55A
Output Power	31.2W	8.5W	5.3W	8.3W
Where Used	SDHU, IRU	SDHU, IRU	SDHU, Balance Sensors, IRU, WL Heater	SDHU, Balance Sensors, IRU, WL Heater

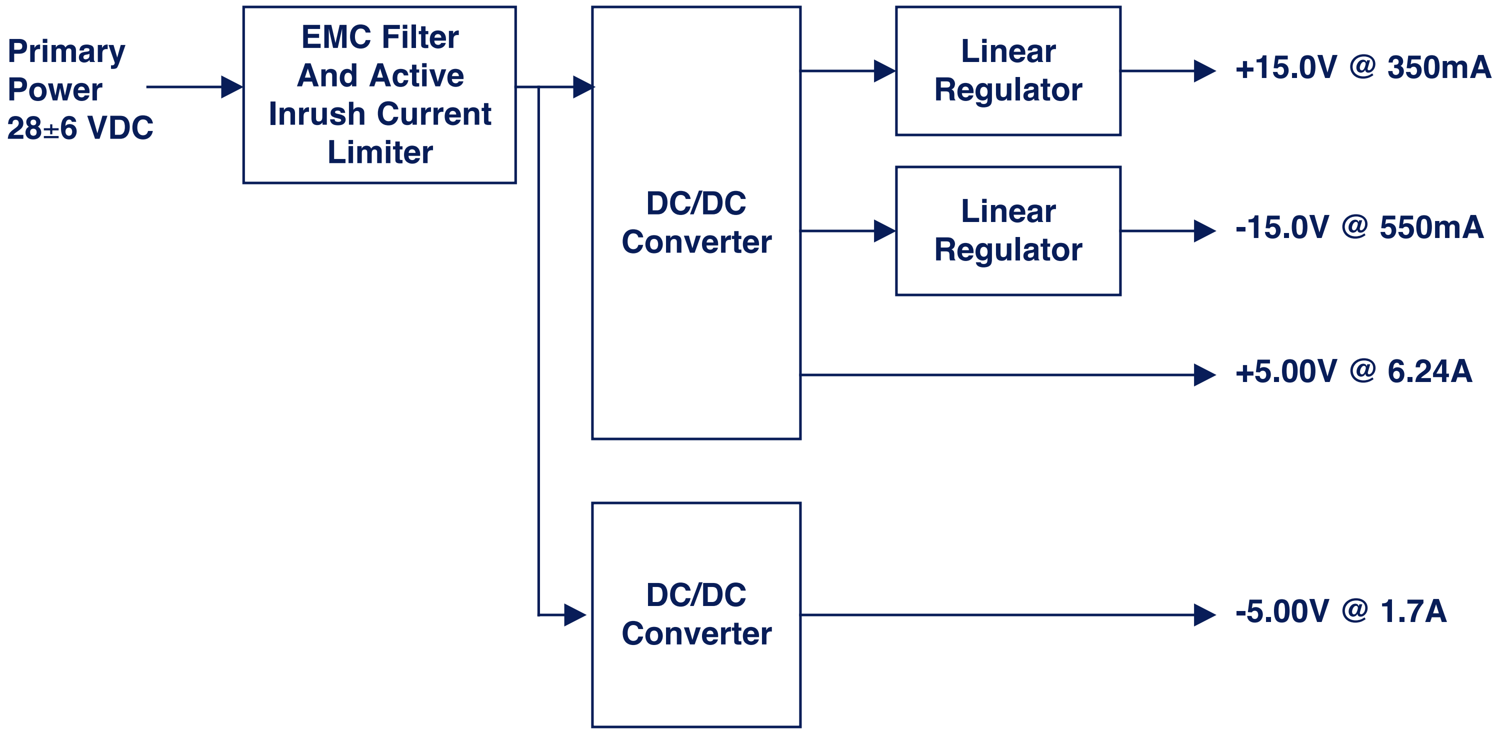
Total Output Power: 53.3W

RDHU Power Converter Output Requirements

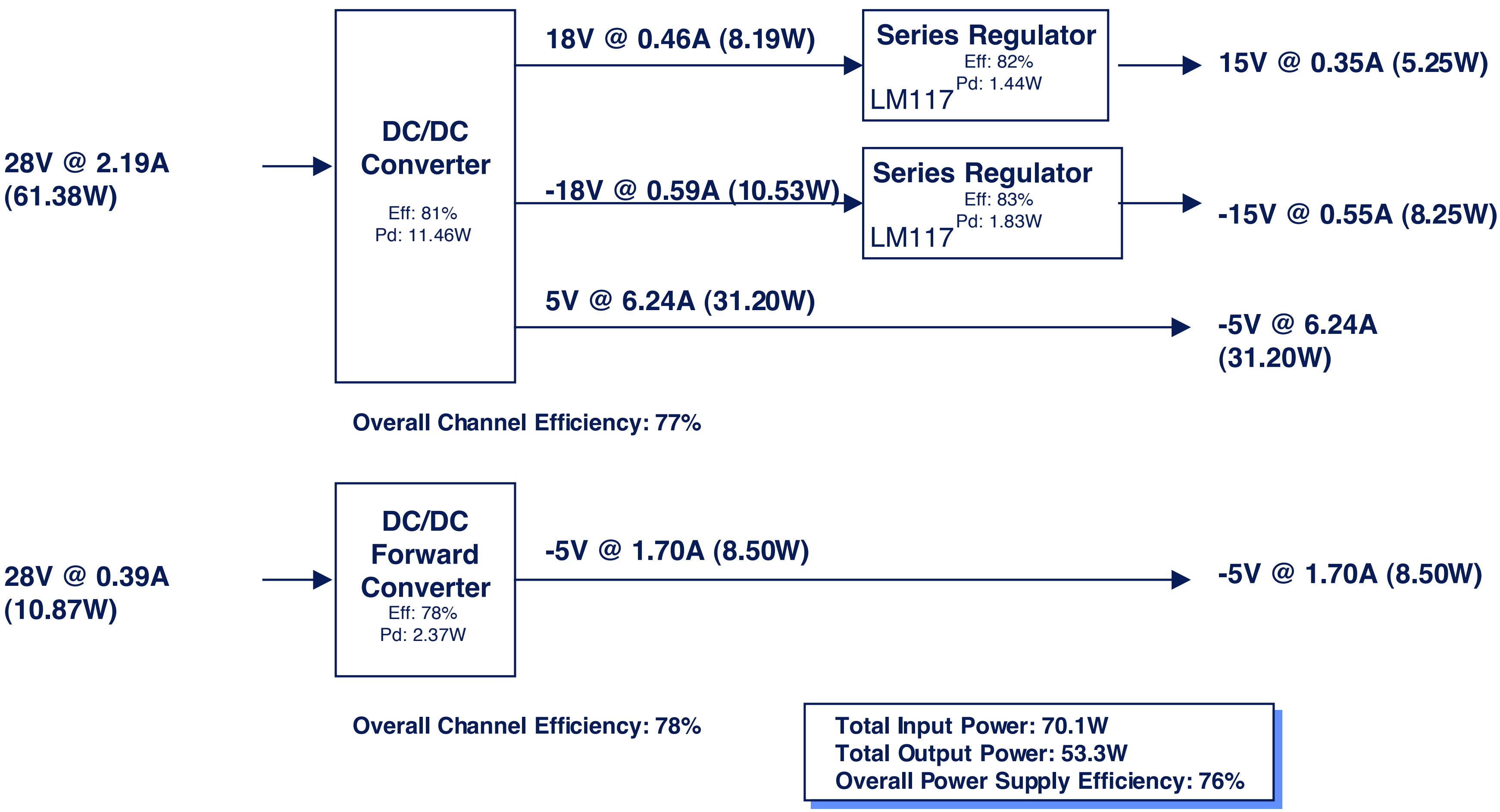
	Output Voltage			
Output Voltage	5.0V	-5.0V	15.0V	-15.0V
Tolerance	5%	5%	5%	5%
Output Ripple Voltage	50mVp-p	50mVp-p	50mVp-p	50mVp-p
Output Current	1.04A	0.06A	0.31A	0.31A
Output Power	5.2W	0.3W	4.6W	4.6W
Where Used	RDHU, GPS	RDHU, GPS	RDHU, GPS	RDHU, GPS

Total Output Power: 14.7W

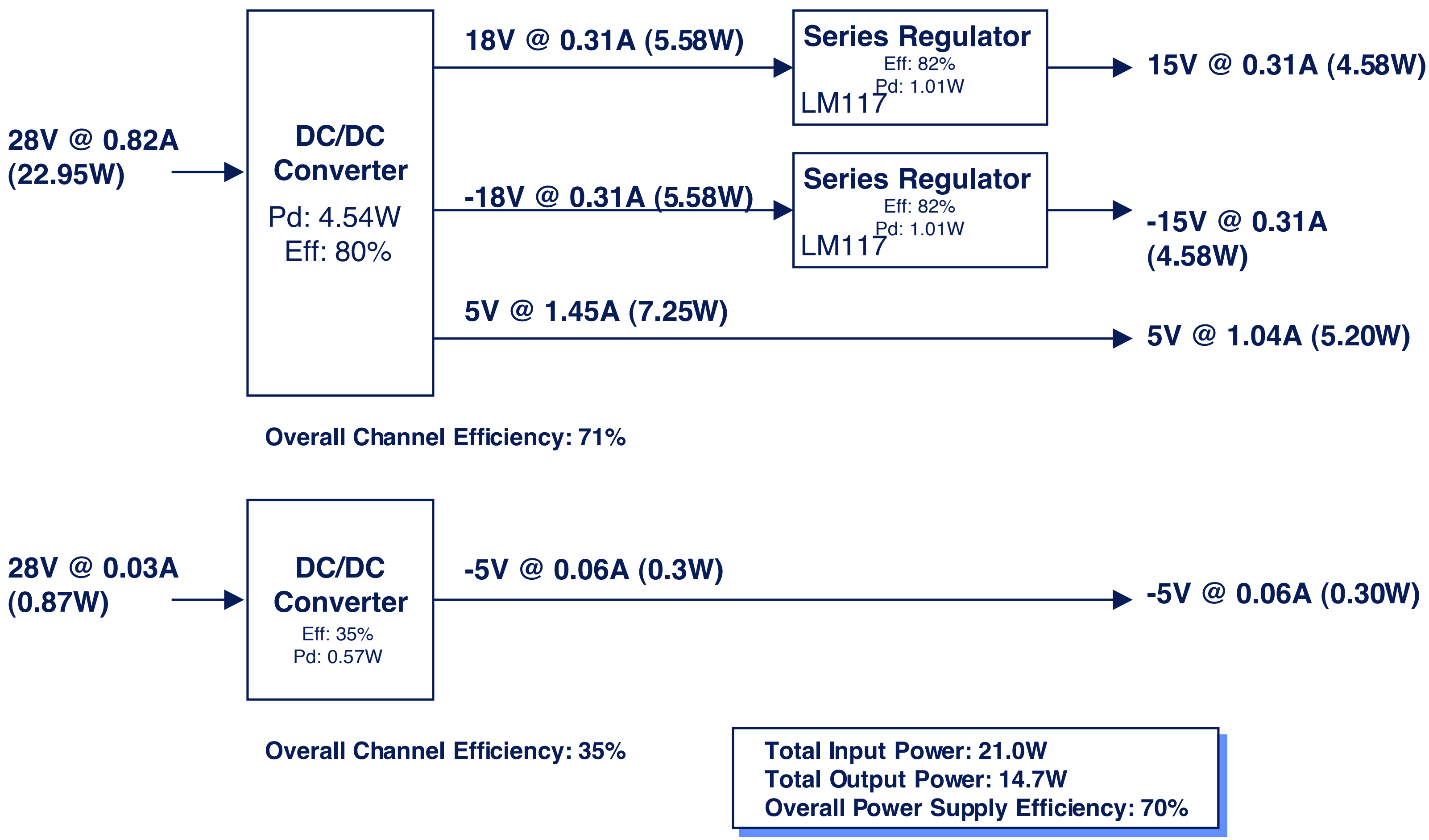
Data Handling System (DHS) Power Supply Block Diagram



SDHU Power Converter Power Budget Diagram (Normal Steady State Load)



RDHU Power Converter Power Budget Diagram (Normal Steady State Load)



Overall Subsystem Power

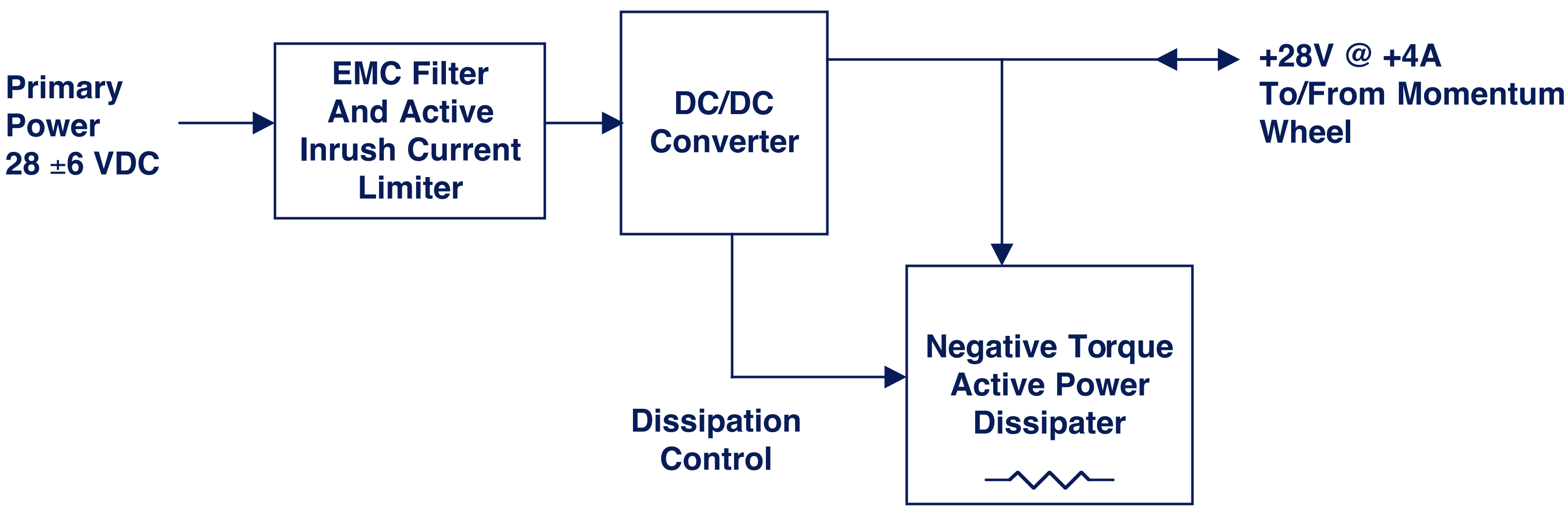
Subsystem	Unit Power	Units	Net Input Power
2 Channel DEU Power	17.0W	2	34.0W
6 Channel DEU Power	40.0W	3	120.0W
SDHU Power	70.1W	1	70.1W
RDHU Power	21.0W	1	21.0W
Total System Power			245.1W

Momentum Wheel Preconverter

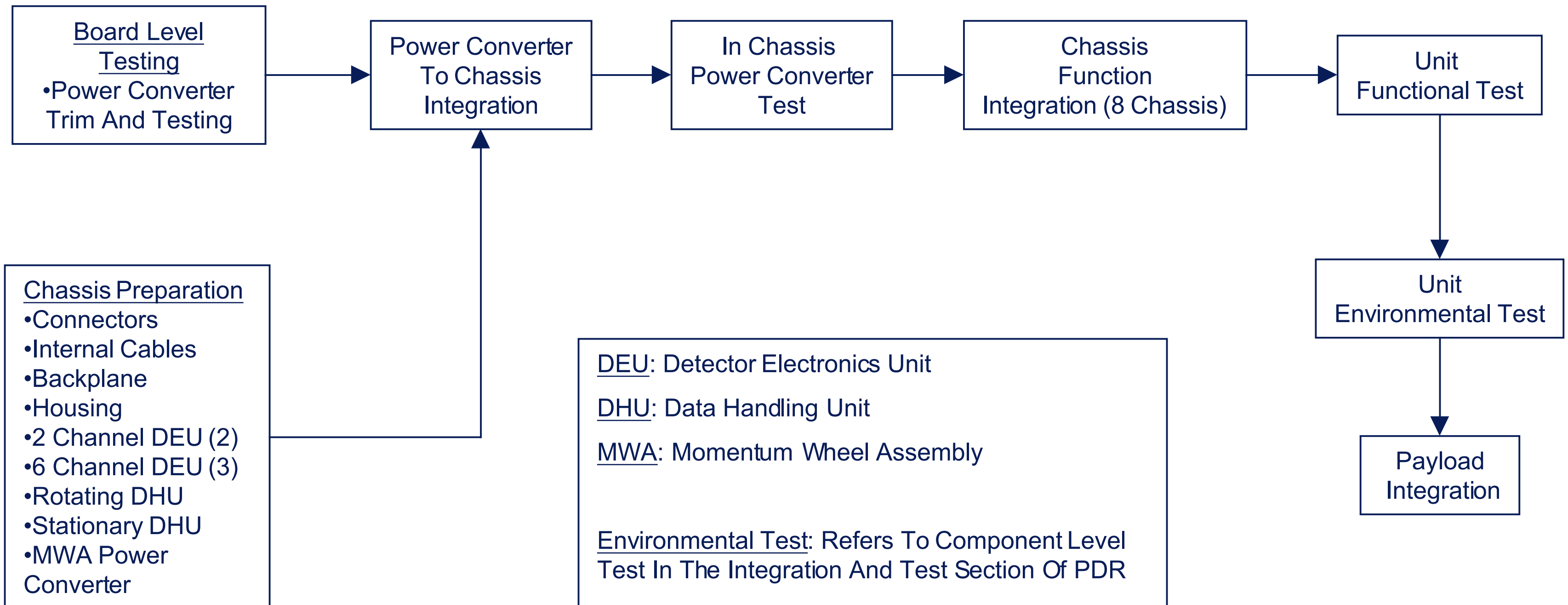
- Preconverter Matches Spacecraft Power Bus To The Requirements Of The Momentum Wheel Power Converter (32 VDC)

- Maximum Output Power: 100 Watts (3.6A @ 28V)

Momentum Wheel Preconverter Block Diagram



Power Converter Integration Flow



DEU: Detector Electronics Unit

DHU: Data Handling Unit

MWA: Momentum Wheel Assembly

Environmental Test: Refers To Component Level Test In The Integration And Test Section Of PDR

Power Converter Test Plan Overview

- Performance Testing
  - Trim And Test Power Converters At Board Level
  - Test Receivers In A Condition That Closely Resembles The System Environment

- Environmental Stress Screening
  - Disclose Weak Parts And Workmanship Defects

Power Converter AGE Requirements

- **Routine Laboratory Equipment**
- **Custom Test Unit Integrates Loads, Switching Functions, And Lab Test Equipment**

Power Converter On-Orbit Operations

- Purpose:
  - Assess Receiver Health
  - Detect Anomalous Operation

- Engineering Data:
  - Temperature and Voltage Monitors

- Process:
  - Monitor Engineering Data To Detect Short Term Effects
  - Perform Trend Analysis To Determine Degradation
  - Archive Engineering Data And Analysis Results

Power Converter Procurement Status

- Receiver Power Converter - BUILD
- Stationary DHU Power Converter - BUILD
- Rotating Power Converter - BUILD
- MWA Power Converter - BUILD

Power Converter EMC/EMI Plan

- Compartmented DEU To Isolate Power And Digital Functions From Audio Processor
- Filter Pins/Connectors On Power Compartment Inputs And Outputs
- Solid Shield Cable Harness, MIL-C-38999, Series 4 Circular Connectors With EMI Backshells
- Cables And Connectors Segregated According To Signal Frequency, Rise Time, And Fall Time
- Power Converter Ripple Specified To Be Consistent With Audio Processor PSRR
- Linear Regulators For LNAs And RFAs

Data Handling System

Stuart Nicholson

Derived Requirements & Compliance

- **Generate Programmable Radiometer Integrator Timing**

Parameter	*6.8 GHz*	*10.7 GHz*	*18.7 GHz*	*23.8 GHz*	*37 GHz*	*Units*
3dB Beamwidth	1.93	1.23	0.70	0.55	0.36	Degrees
Sample Rate/Chnl	183.6	288.9	504.8	642.5	998.9	S/Sec
Integration Time	5.447	3.462	1.981	1.556	1.001	ms

  - **Synchronize Sampling to Start-of-Rotation, By Delayed Amount**
  - **Programmable Integrator Dump Time, Number of Samples Per Spin**
  - **Design is Fully Compliant**

- **Associate Integrator Timing and Spin Angle to UTC with 11 μs Accuracy**

Parameter	*Value*	*Units*	*Conditions*
Tachometer Timetag Resolution	0.289	μs	RMS for 1 μs resolution
Synchronization Resolution	0.289	μs	RMS for 1 μs resolution
GPS PPS Accuracy	1.000	μs	RMS, SA On
GPS PPS Timetag Resolution	0.289	μs	RMS for 1 μs resolution
TCXO Stability	0.001	μs	1 Second Allan Variance
RSS Total	1.118	μs	

11 μs Derived From Position Determination Allocation to SA Spin Control Subsystem of 0.002° [(0.002° / 360°) x (60 secs/min / 29.6 RPM)]

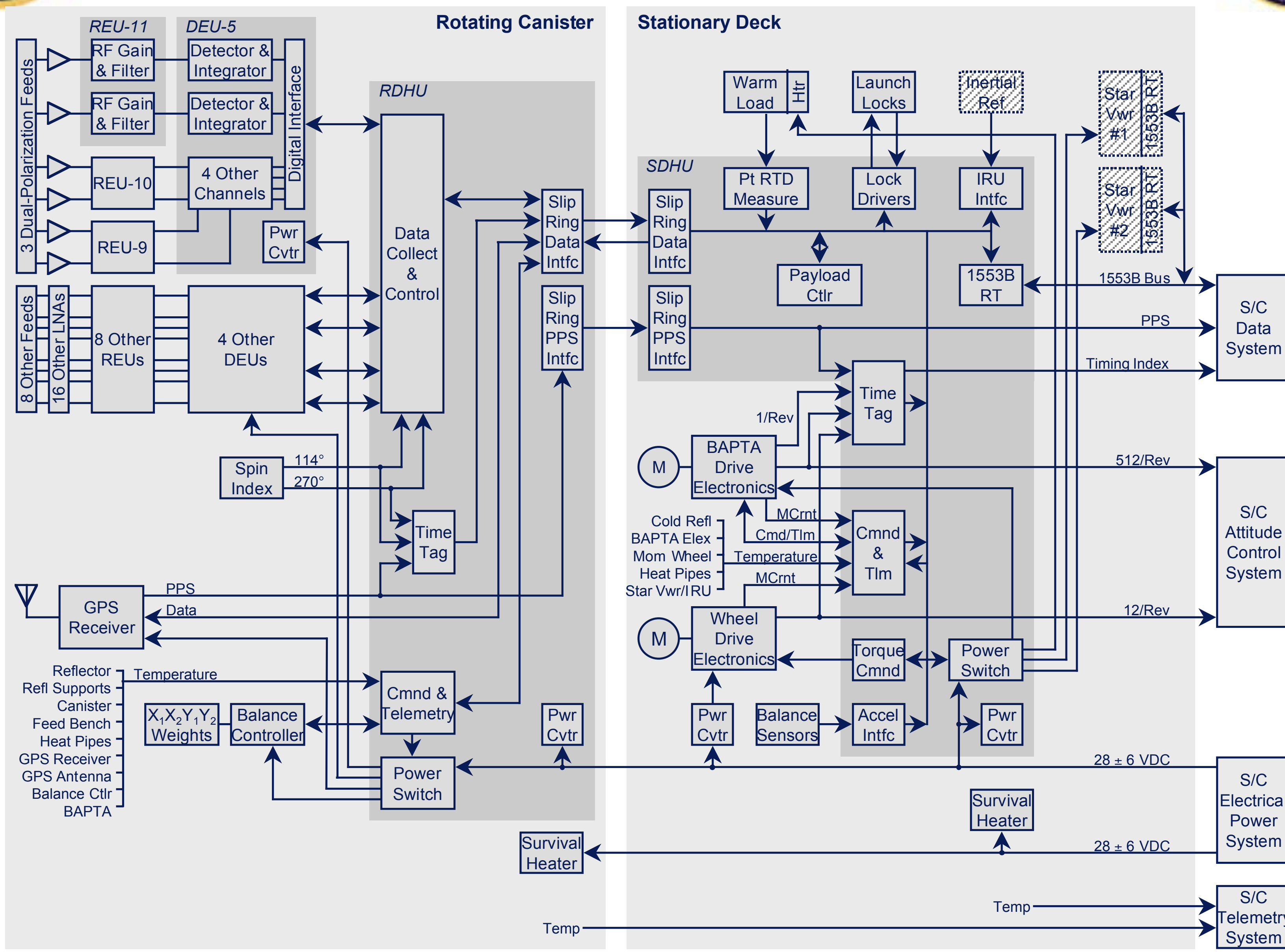
  - **Design is Fully Compliant**

- **Measure Warm Load Temperature to 0.0625K Accuracy, 0.05K Resolution**
- **Operate For 3 Years in an Environment of -20°C to +60°C, 20K Rads Si**
  - **Design is Fully Compliant with 90 mil Aluminum Housing**

Trade Studies Update from SRR

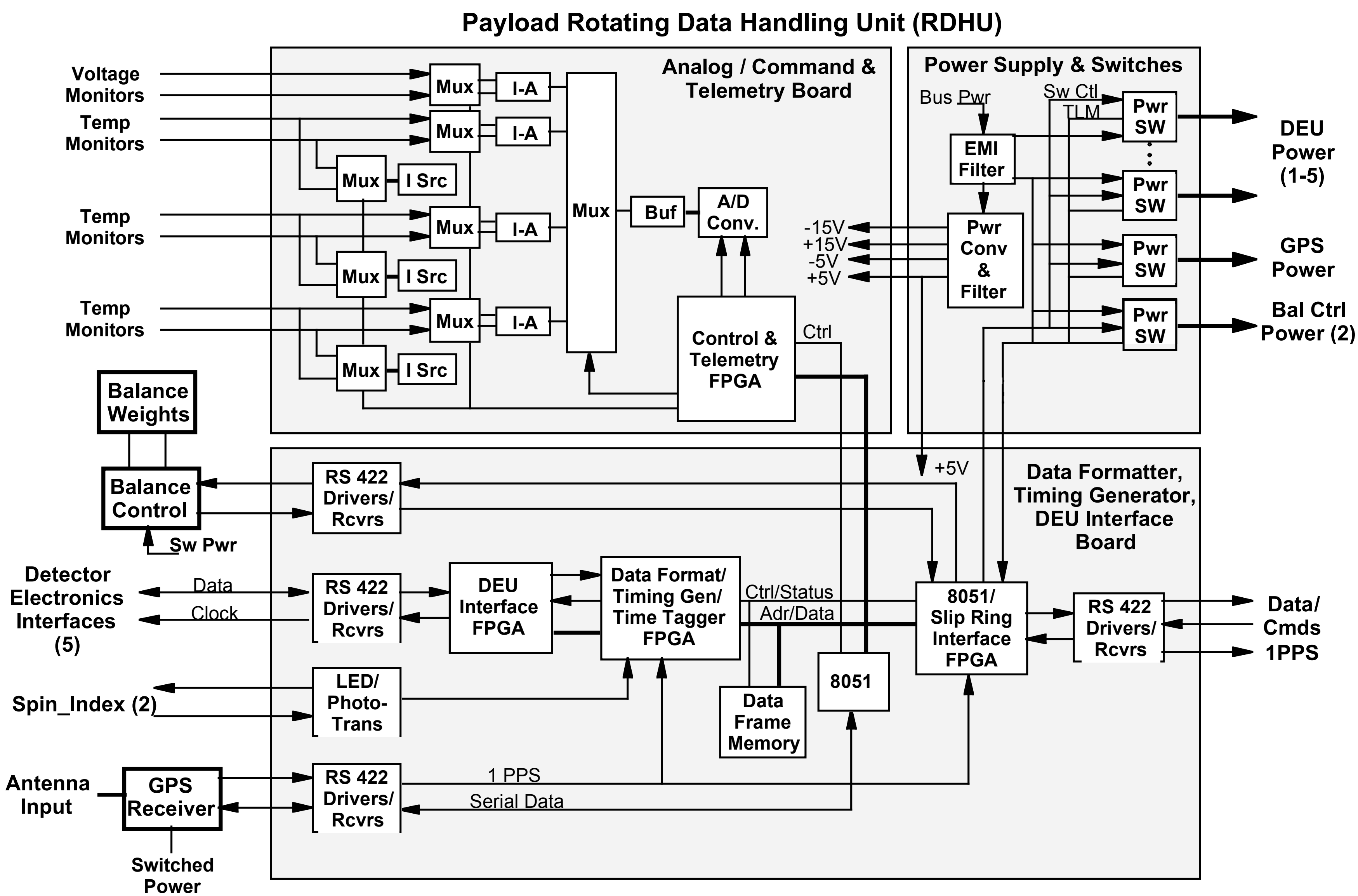
- Processor Make/Buy Trade
  - Selection Criteria
    - Flight Qualified Design, Heritage Preferable
    - At Least 20 MIPS, 2MB RAM, 2MB EEROM, VME Interface, VxWorks
    - Acceptable EBB and Flight Unit Delivery Schedule
  - Selected - Harris SSPM R3000 Board
- Rotating vs Stationary Location of Units
  - Single Data Handling Unit in Rotating Canister
    - Pros - Single Unit Development
    - Cons - Excessive Slipring Count; Complex, Low-level Spacecraft Interface to Stationary Components
    - Selected - Rotating and Stationary Data Handling Units
  - GPS Receiver Located in Rotating Canister for Full Satellite View
- RIU vs Embedded Telemetry
  - Existing Standalone Command and Telemetry Unit (RIU)
    - Cons - Excessive Capability, Power, Weight
  - Selected - Embedded T&C Design

DHS Detailed Block Diagram

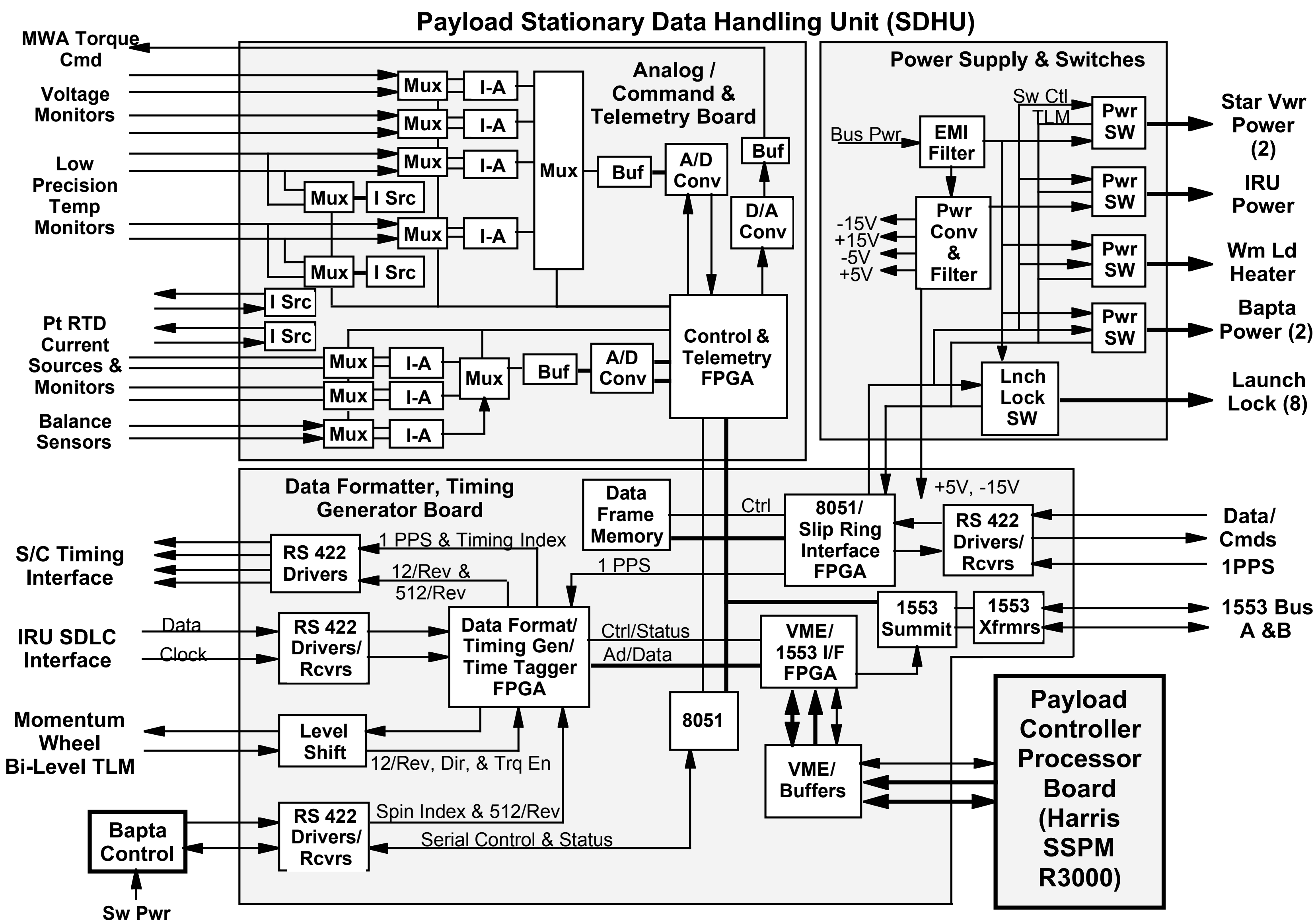


980610_WS_PRD_DHU.4

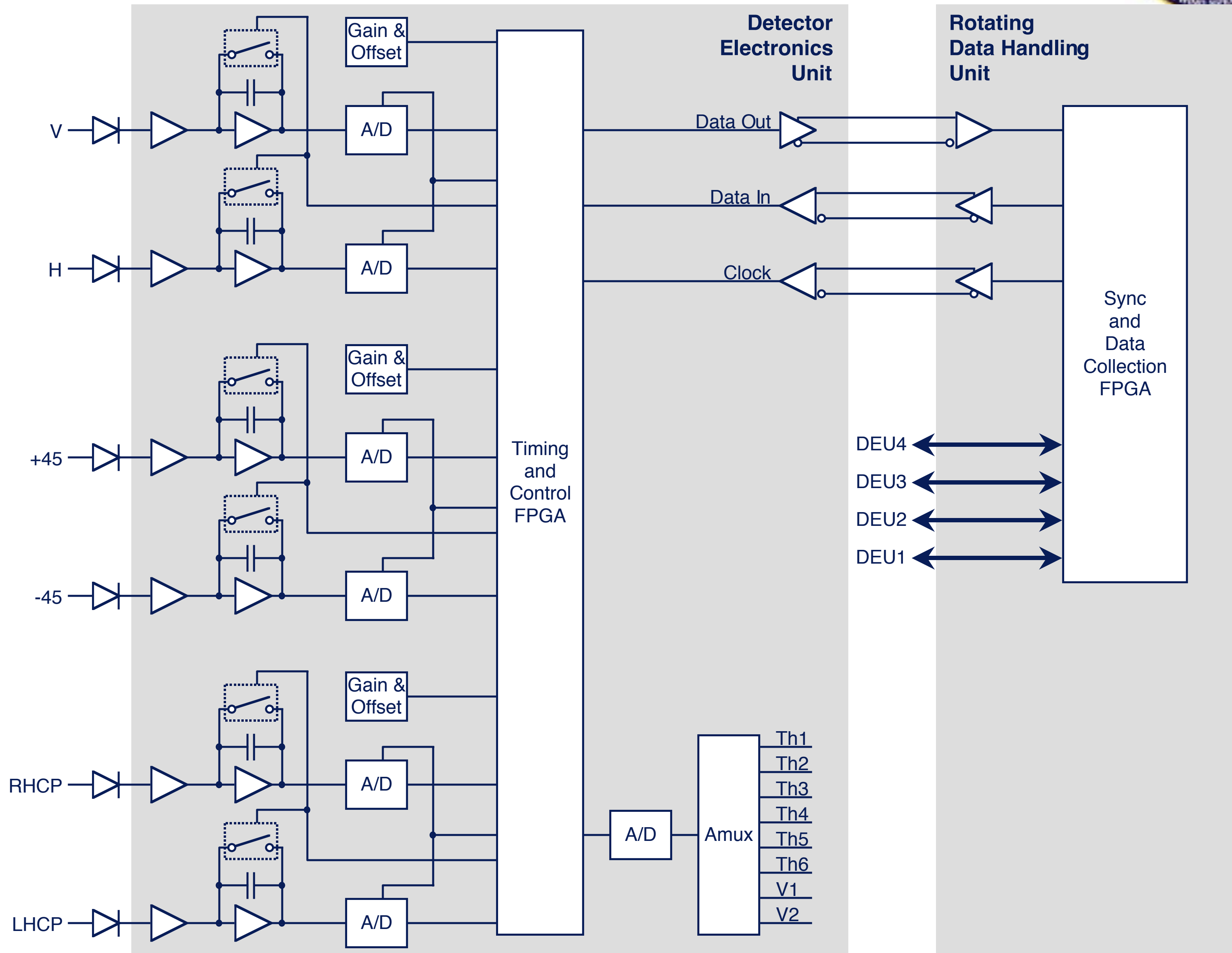
RDHU Block Diagram



SDHU Block Diagram



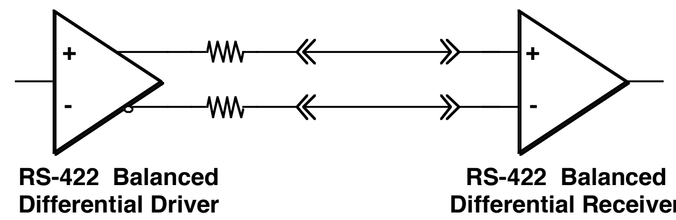
DEU/RDHU Interface Diagram



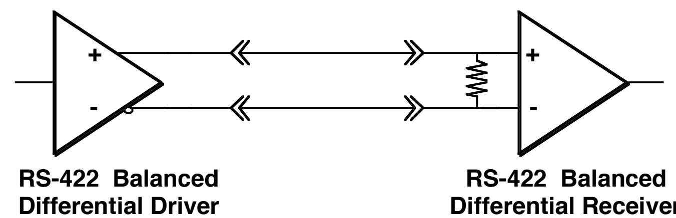
980610_WS_PRD_DHU.7

DHS Interface Details (1 of 3)

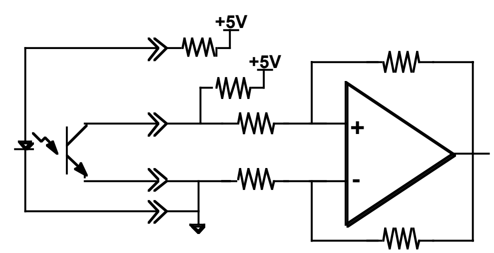
- **Series Terminated RS-422**
  - DEU-RDHU
  - Balance Controller
  - RDHU-SDHU Slip Ring
  - BAPTA Drive Electronics
  - Inertial Reference Unit
  - Spacecraft 1PPS, Timing Index, 512/Rev Tach, and 12/Rev Tach



- **Parallel Terminated RS-422**
  - GPS Receiver

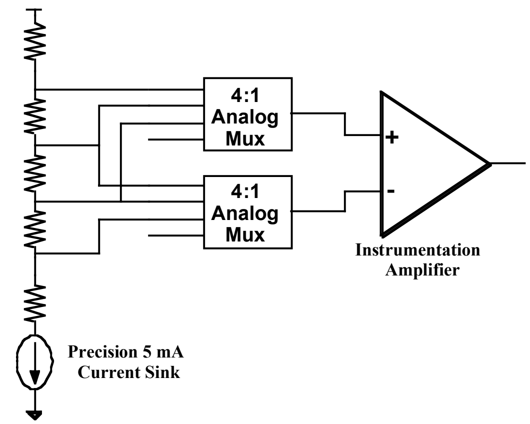


- **RDHU-Spin Index**

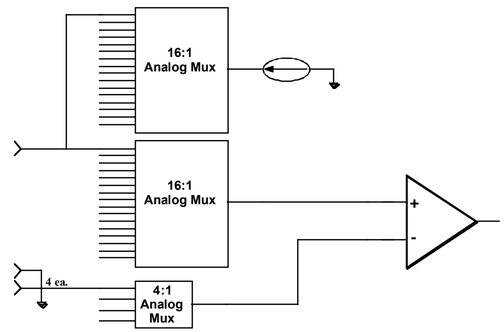


DHS Interface Details (2 of 3)

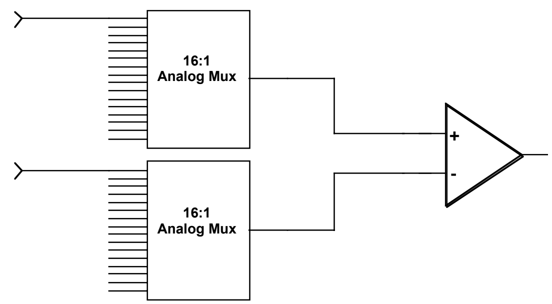
- **Warm Load Precision Temperature Platinum RTD**



- **Non-Precision Temperature Thermistor**

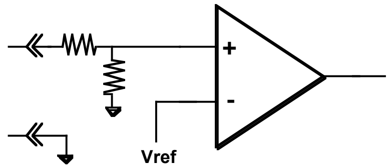


- **Active Analog Voltage Telemetry**

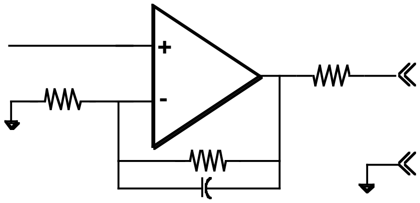


DHS Interface Details (3 of 3)

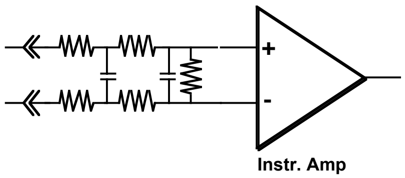
- **Bi-Level Telemetry**



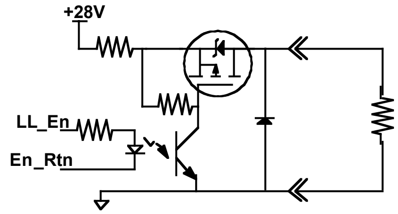
- **SDHU-Momentum Wheel Torque Command**



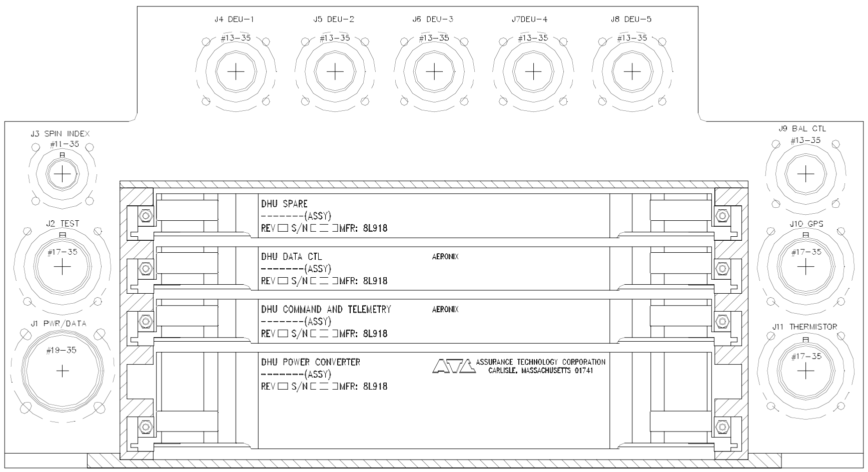
- **SDHU-Balance Sensor**



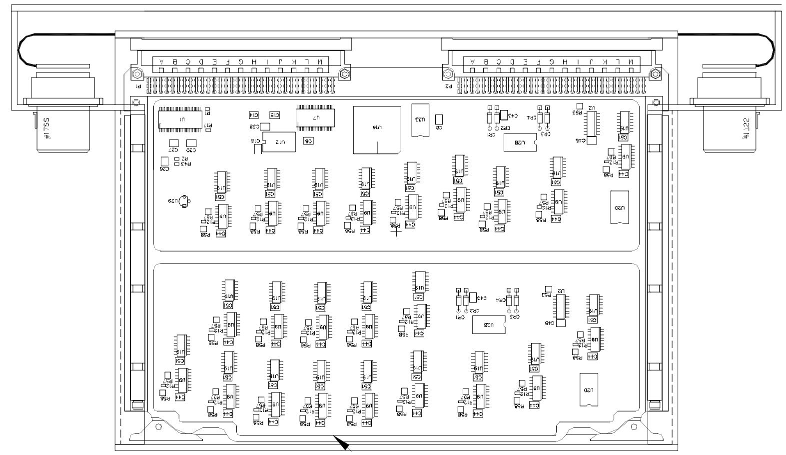
- **Launch Lock Release and Prime Power Switching**



RDHU/SDHU Mechanical Drawings

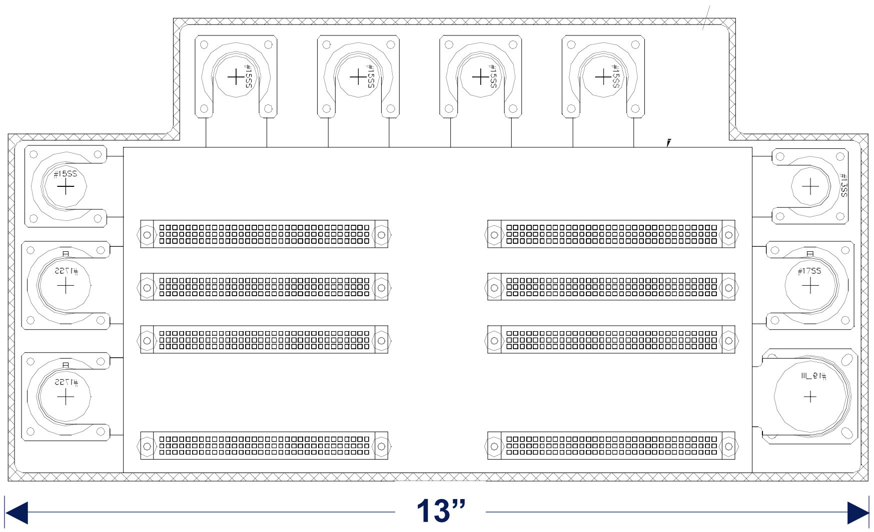


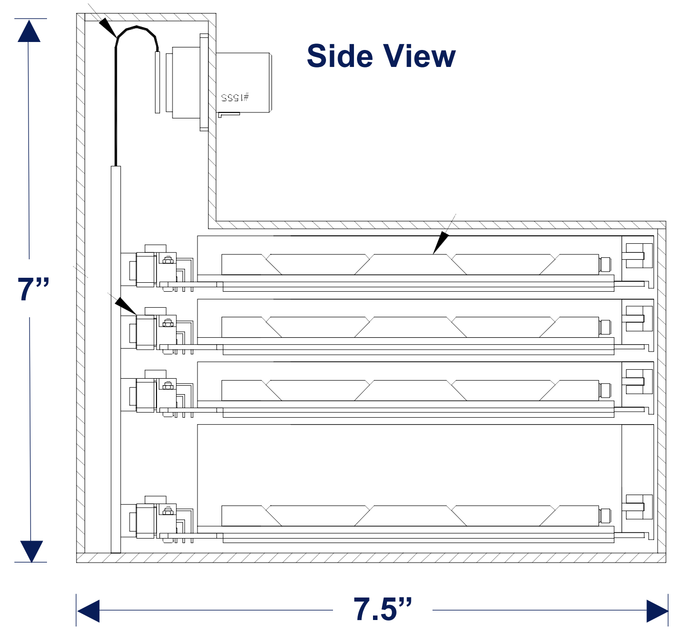
Front View



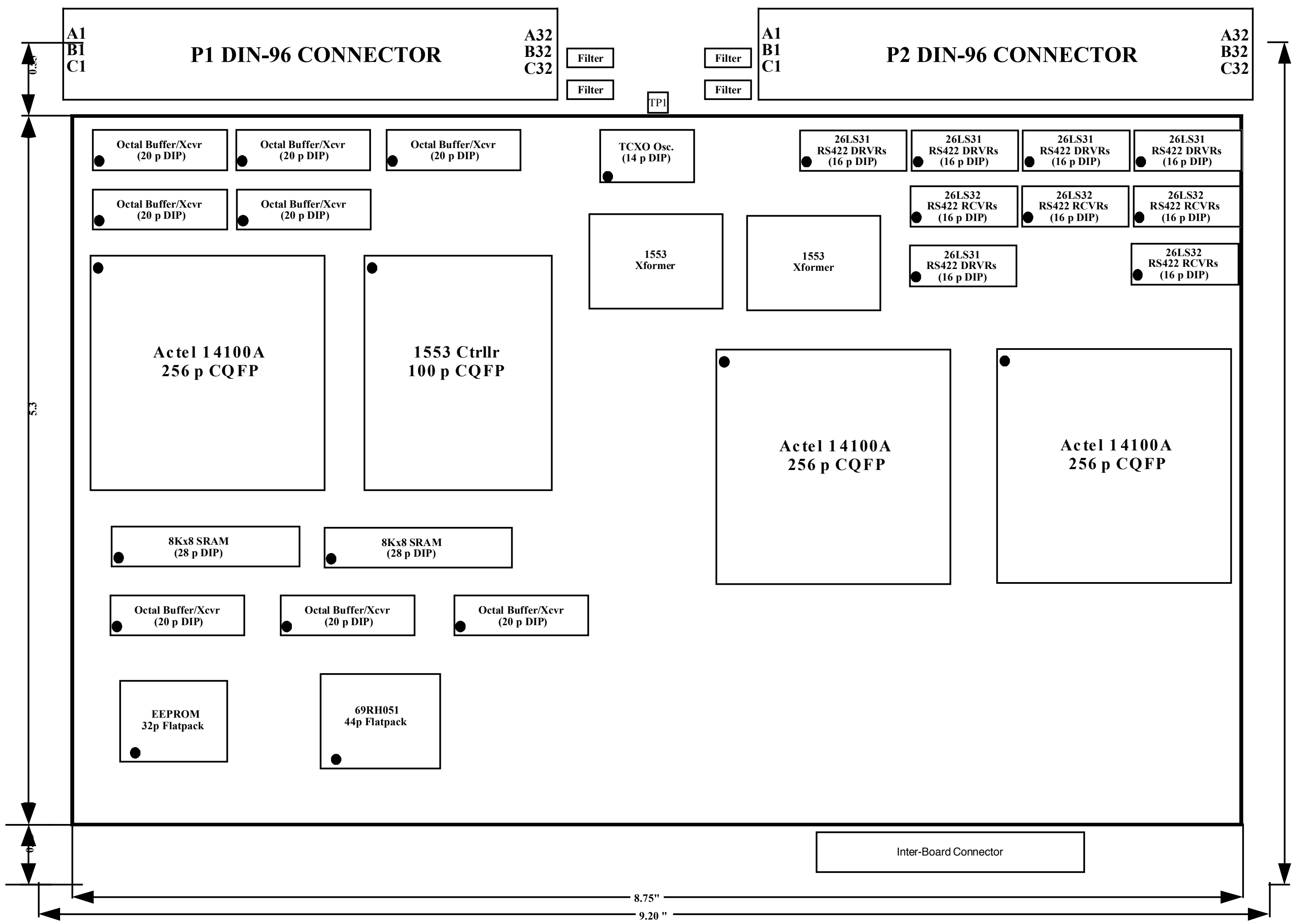
Top View

Rear View

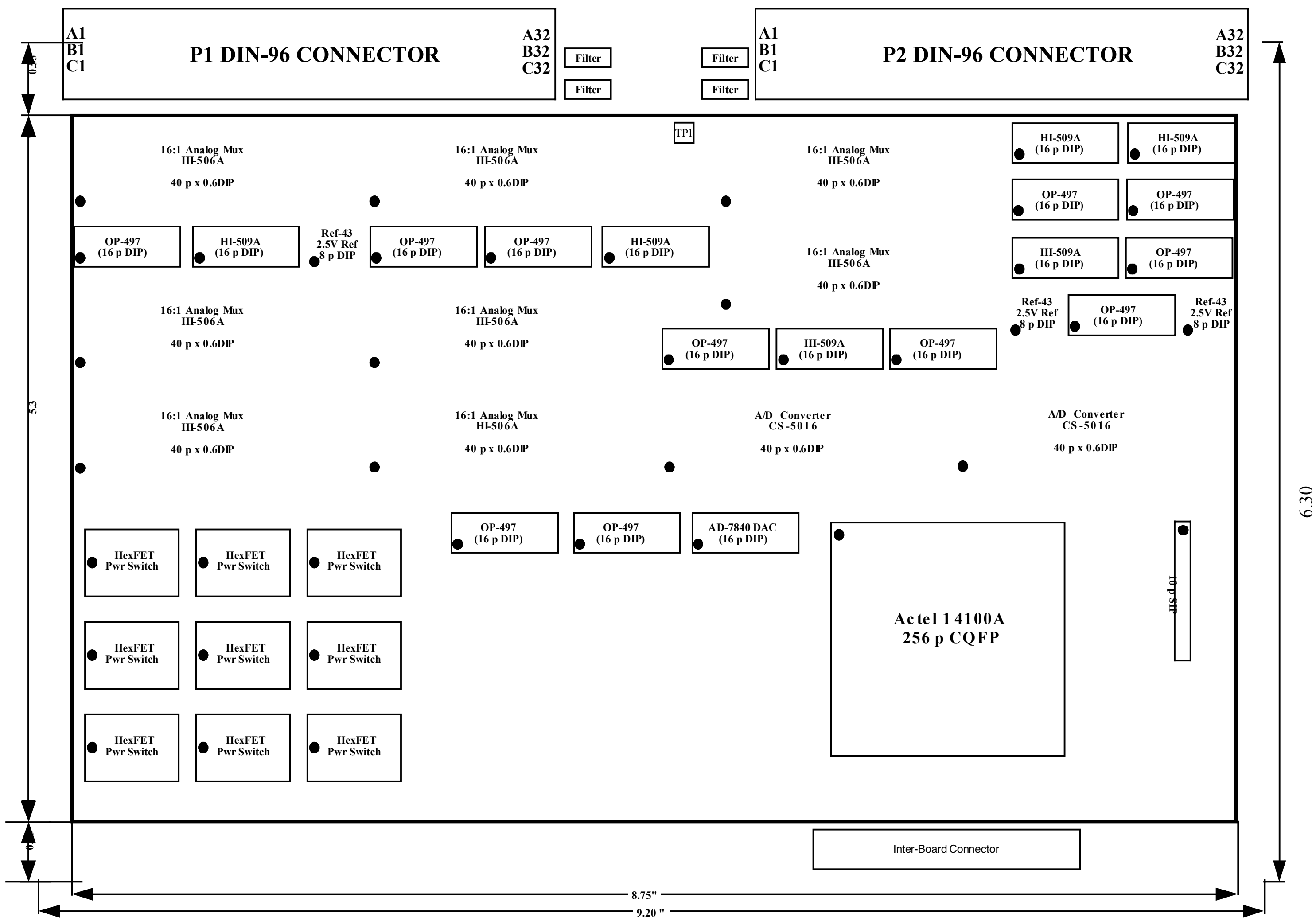




Digital Board Placement



Analog Board Placement



Analog Telemetry Error Analysis

- ## Pt RTD Measurement Error Terms

Error Source	Error Type	Temp Range	Error Magnitude			Requirement	Margin
			(V)	A/D LSB's	(Deg C)	(Deg C)	(Deg C)
Op Amp Residual Offset	Bias		7.70E-06	0.03	1.23E-04		
Op Amp Offset Temperature Variation	Random	0 - 50 C	1.37E-04	0.45	2.19E-03		
Current Source Temperature Variation	Random	0 - 50 C	1.20E-03	3.93	1.92E-02		
RSS'd Random Terms			**1.21E-03**	**3.96**	**0.019**		
Total (RSS + Residual Bias)			**1.22E-03**	**3.99**	**0.019**	**0.0625**	**0.043**

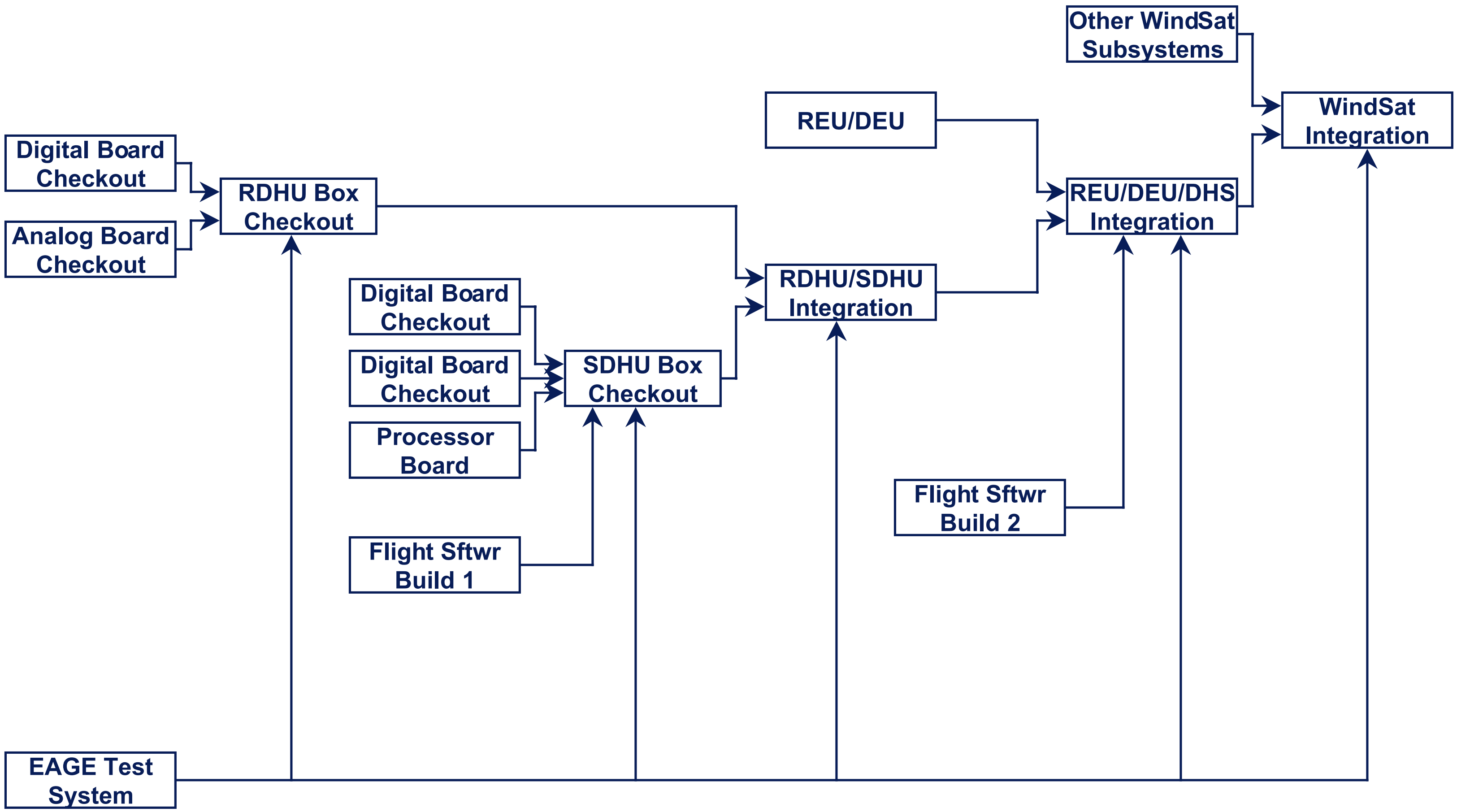
- ## Thermistor Measurement Error Terms

Error Source	Error Type	Temp Range	Error Magnitude			Requirement	Margin
			(V)	A/D LSB's	(Deg C)	(Deg C)	(Deg C)
Op Amp Residual Offset	Bias		3.30E-06	0.01	1.25E-04		
Op Amp Offset Temperature Variation	Random	0 - 50 C	1.00E-04	0.16	3.78E-03		
Current Source Temperature Variation	Random	0 - 50 C	6.00E-03	9.83	2.27E-01		
RSS'd Random Terms			**6.00E-03**	**9.83**	**0.227**		
Total (RSS + Residual Bias)			**6.00E-03**	**9.84**	**0.227**	**1.00**	**0.773**

- ## Voltage Telemetry Error Terms

Error Source	Error Type	Temp Range	Error Magnitude	
			(V)	A/D LSB's
Op Amp Residual Offset	Bias		5.00E-07	0.00
Op Amp Offset Temperature Variation	Random	0 - 50 C	2.50E-05	0.04
Gain Resistors Temperature Variation	Random	0 - 50 C	6.25E-04	1.02
RSS'd Random Terms			**6.25E-04**	**1.02**
Total (RSS + Residual Bias)			**6.26E-04**	**1.03**

DHS Integration Flow



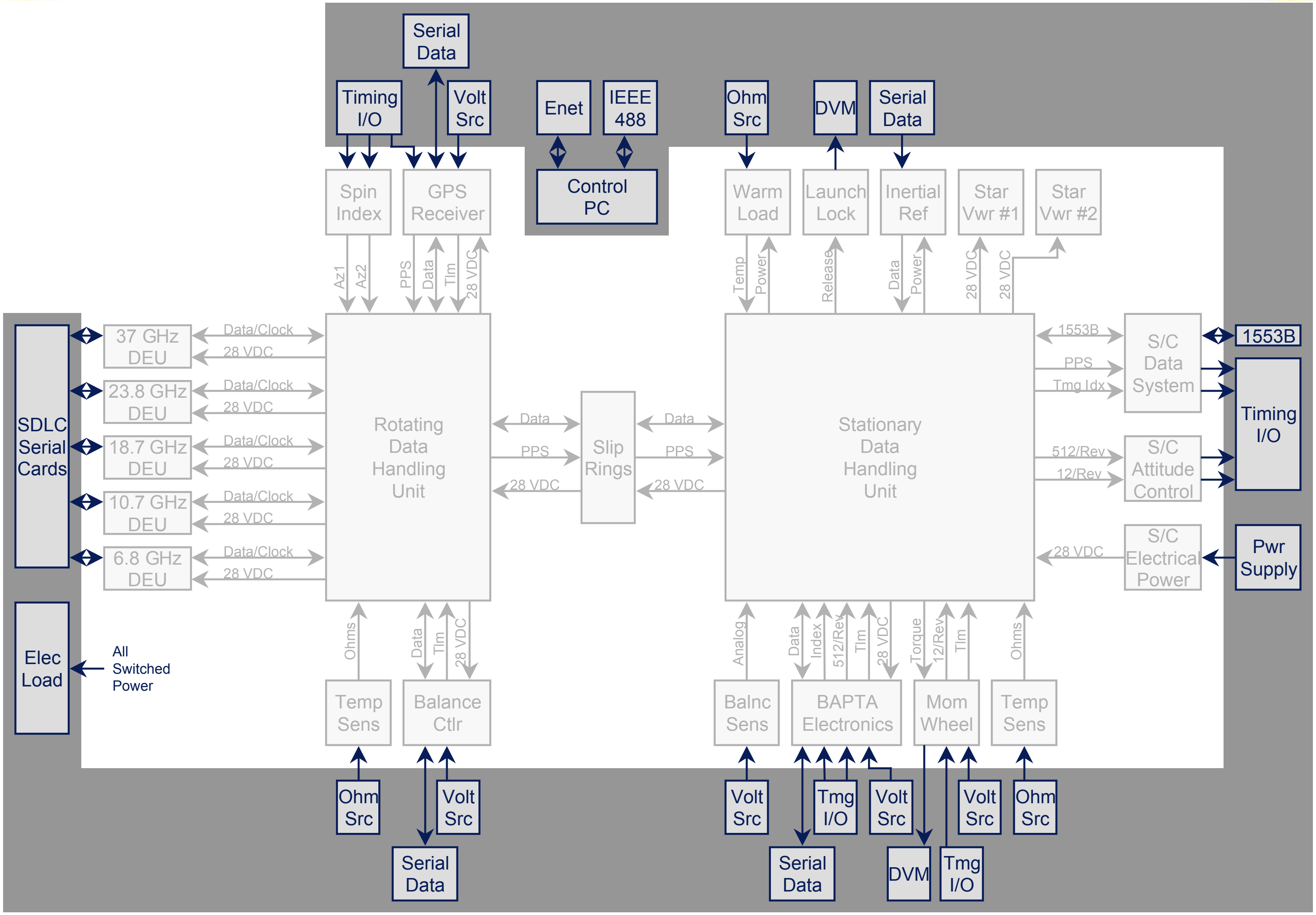
Test Plan Overview - Design Verification

- Performance Verified Through Test and Worst Case Analysis
- Interfaces Verified Through Functional Testing and Waveform Measurement
- EMI/EMC Box Level Testing
- Vibration and Thermal Testing at Box Level
- Shock Verified at System Level

DHS EMI/EMC Mitigation

- Digital Receiver-to-Data Handling System Interface Selected
  - All Analog Signals Contained Within One Shielded Assembly
  - Differential Interfaces Minimizes Signaling Current Transfer, EMI Radiation and Susceptibility
- RDHU and SDHU Contain EMI Filters At Primary Power Interfaces
- EMI Filters and Power Switches for External Loads Housed Inside "Dirty Signal" Compartment Separate From All Other Circuitry
- Lowpass Filters on All Low Rate Analog Telemetry Inputs
- Oversampled, Digitally-Integrated Slipring Data Interfaces Reduces Susceptibility to Interfering Noise
- Warm Load Heater Uses Filtered Regulated Power - No Switching Power Supply Noise

DHS AGE Requirements



DHS Procurements/Status

- Rotating Data Handling Unit - Build
- Stationary Data Handling Unit - Build
- Processor Card - Buy
- Long Lead Items
  - Harris SSPM Processor Board - On Order
  - FPGA Devices - On Order

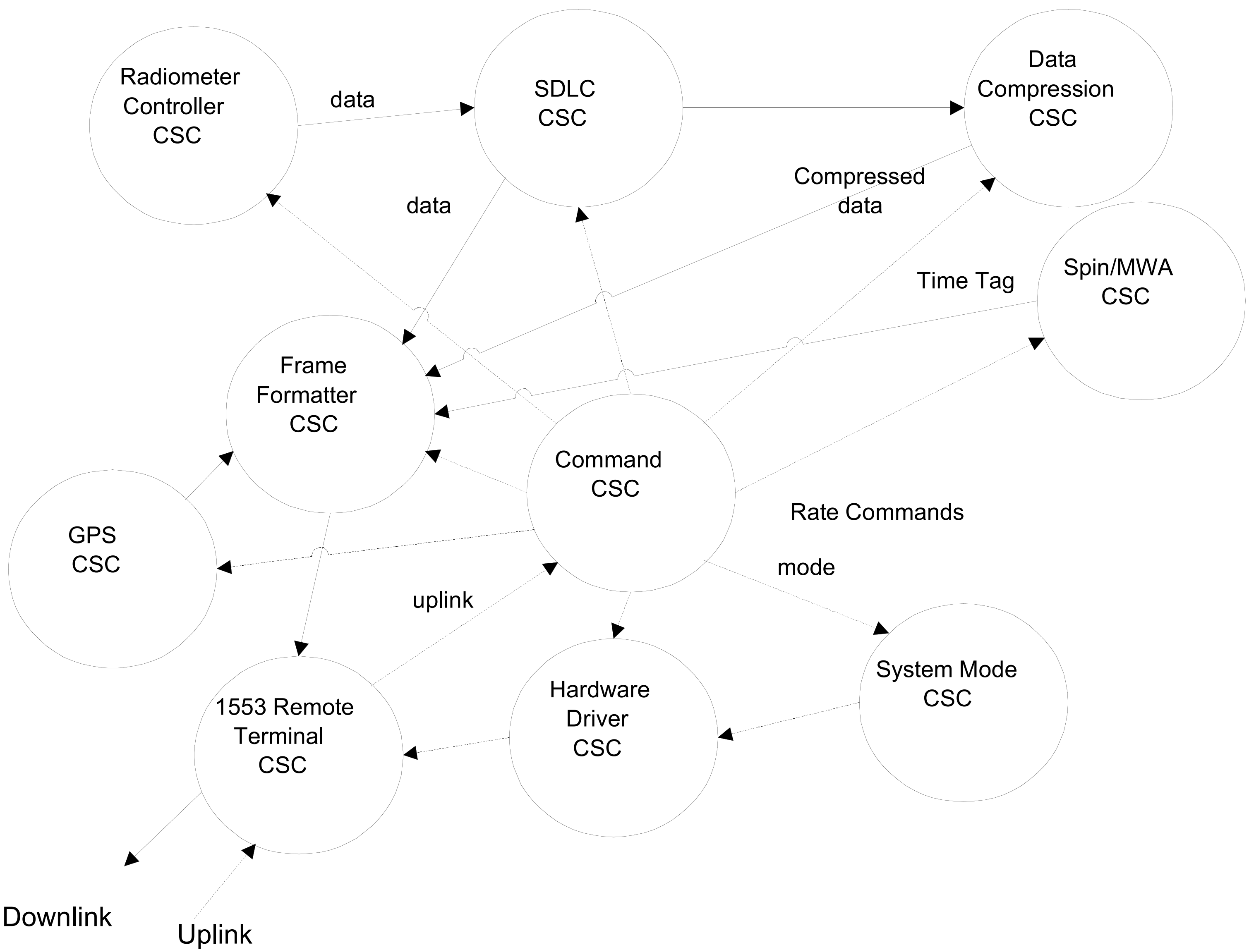
Software Overview

Crossland

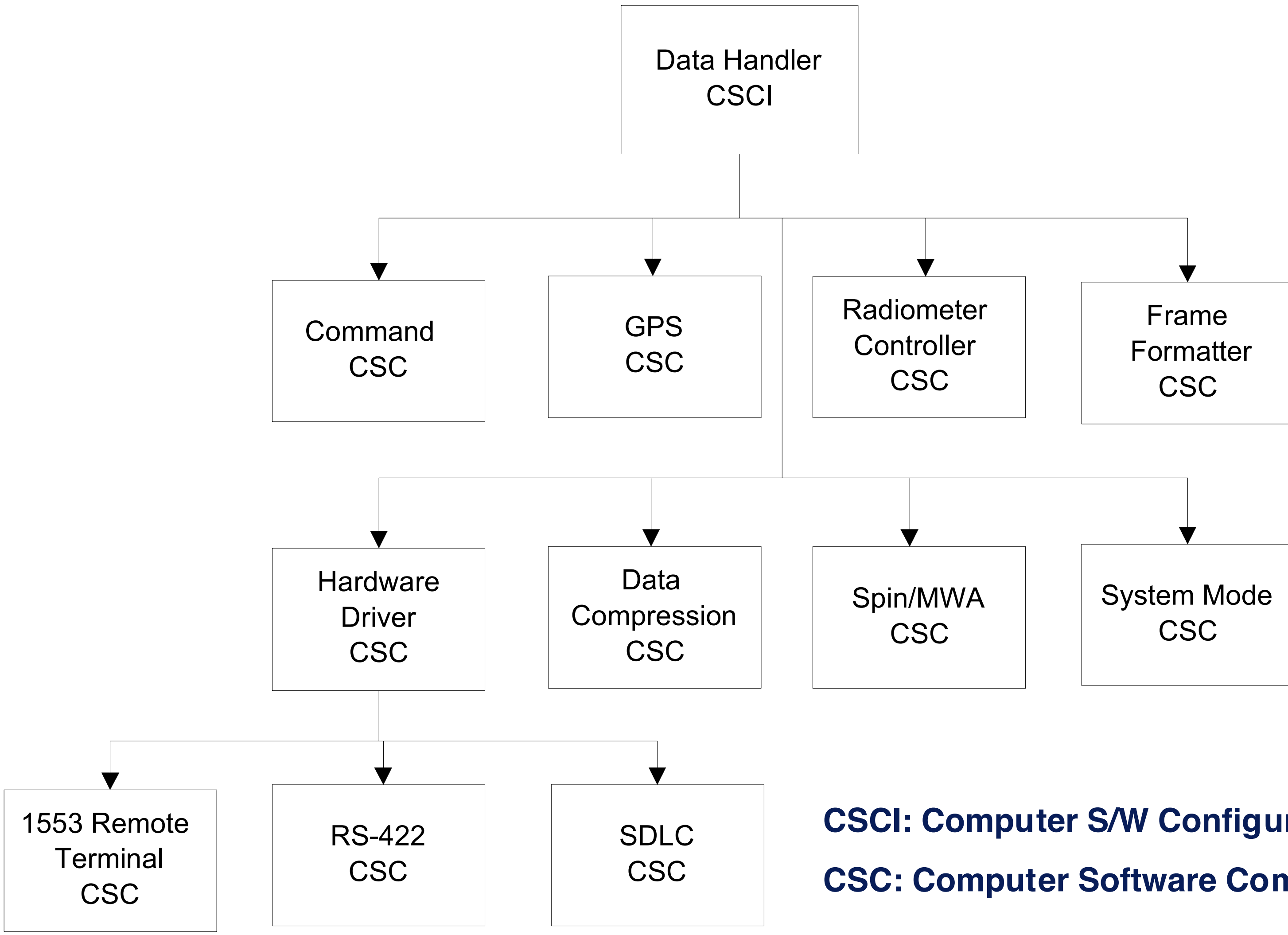
Overview

- Telemetry Data Acquisition
  - Radiometer Data
  - Low Rate Data
- Data Compression of Radiometer Data
- Frame Formatting
- Command Interpretation and Distribution
- BAPTA and momentum wheel control
- Bus Interface Control
  - SDLC, 1553, RS-422
- Radiometer, GPS control

SDHU CSCI Overview



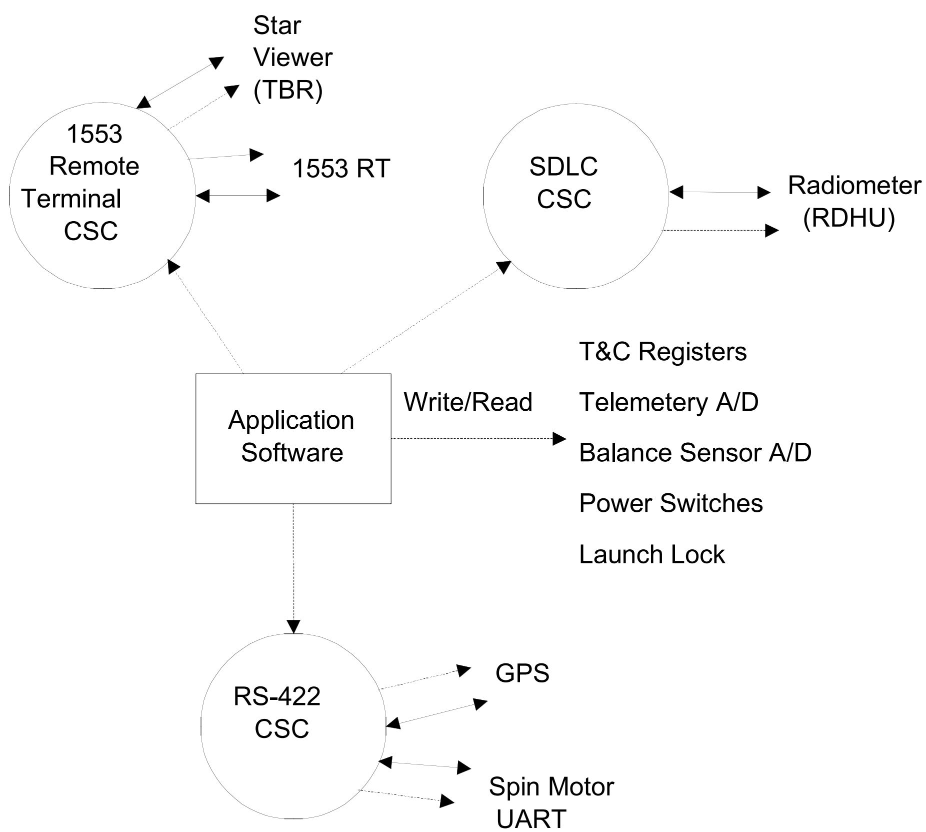
Data Handler CSCI



CSCI: Computer S/W Configuration Item

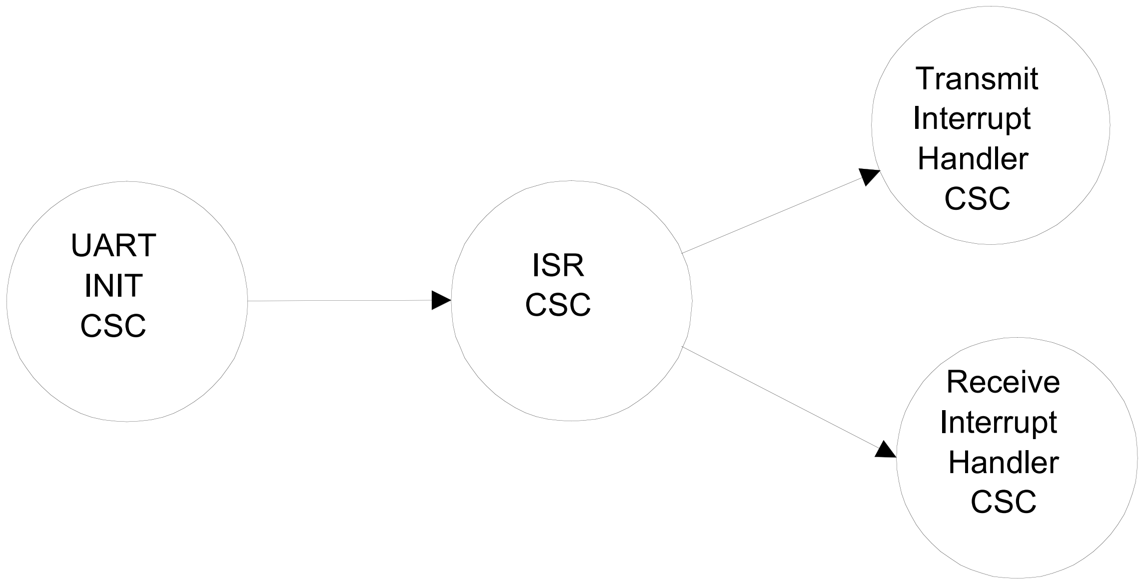
CSC: Computer Software Component

Hardware Driver CSC



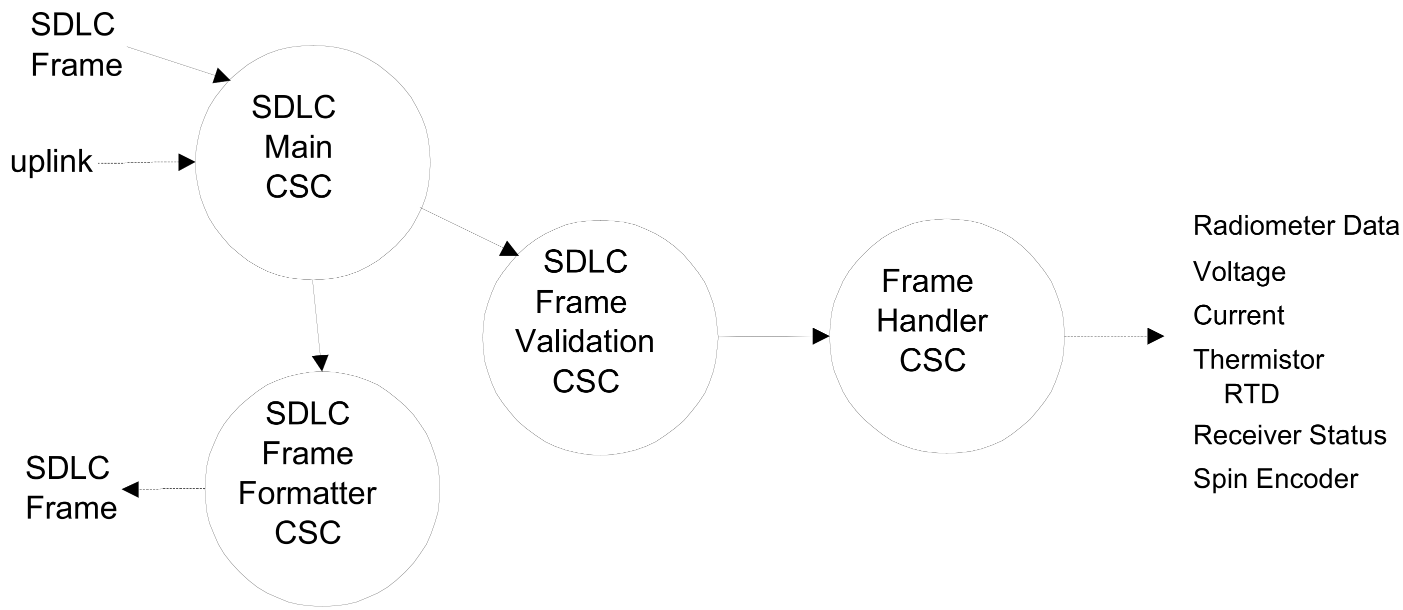
- **All Registers Will Be Initialized by the Hardware Driver CSC**
- **All Registers Are Memory Mapped**

RS-422 CSC



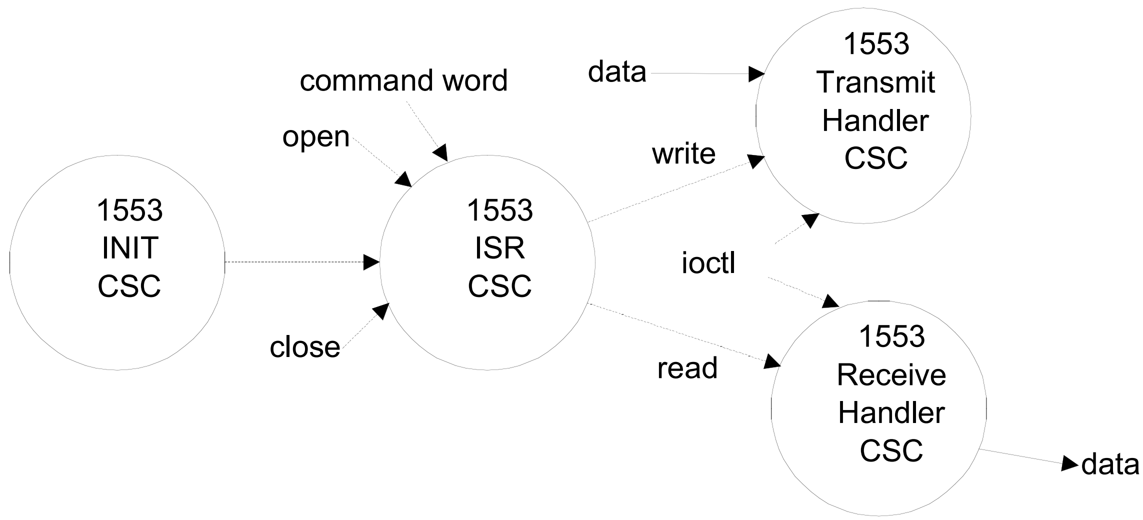
- **UART INIT CSC - Set Baud Rate, Data Format, Initialize Registers**
- **ISR CSC - Reads Interrupt Status Register. Calls Interrupt Handlers. Clears Interrupts**
- **Transmit Interrupt Handler CSC - Get Transmit Characters From Ring Buffer**
- **Receive Interrupt Handler CSC - Put Receive Characters Into a Ring Buffer**

SDLC CSC



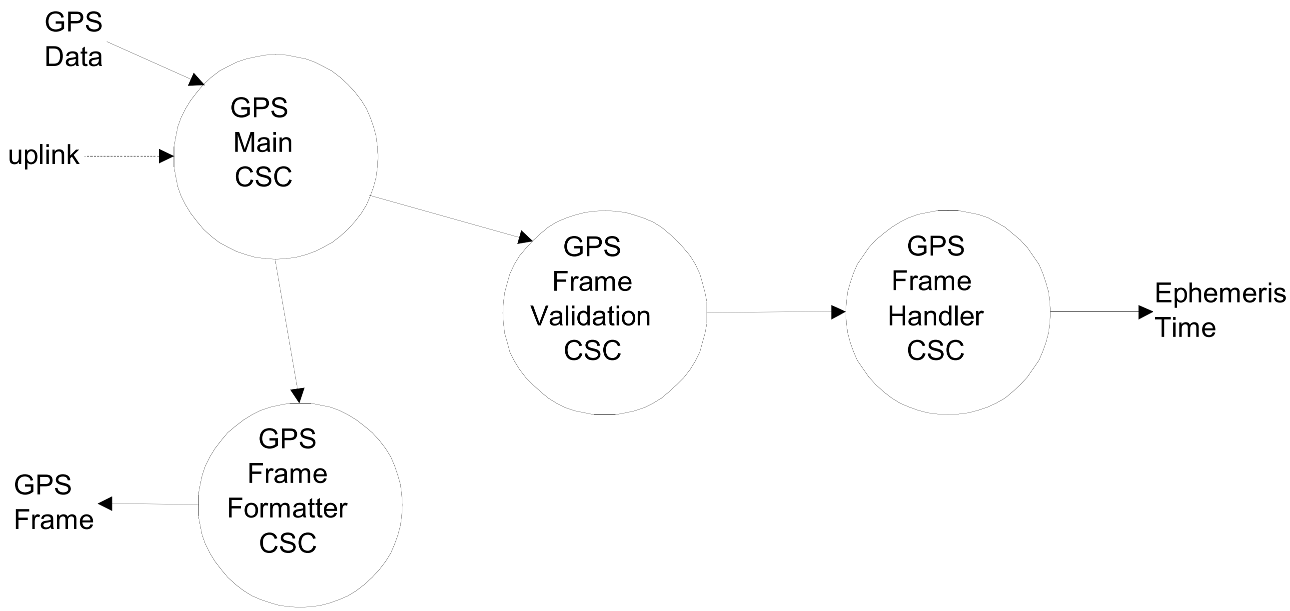
- **SDLC Main CSC - Manages Incoming and Outgoing Messages**
- **SDLC Frame Validation CSC - Validates the Received Frame by Checking CRC**
- **SDLC Frame Handler CSC - Recovers Data. Decodes Header and Writes Data to Memory Based on Header**
- **SDLC Frame Formatter CSC - Formats a SDLC Frame With Header, and Data**

1553 Remote Terminal CSC



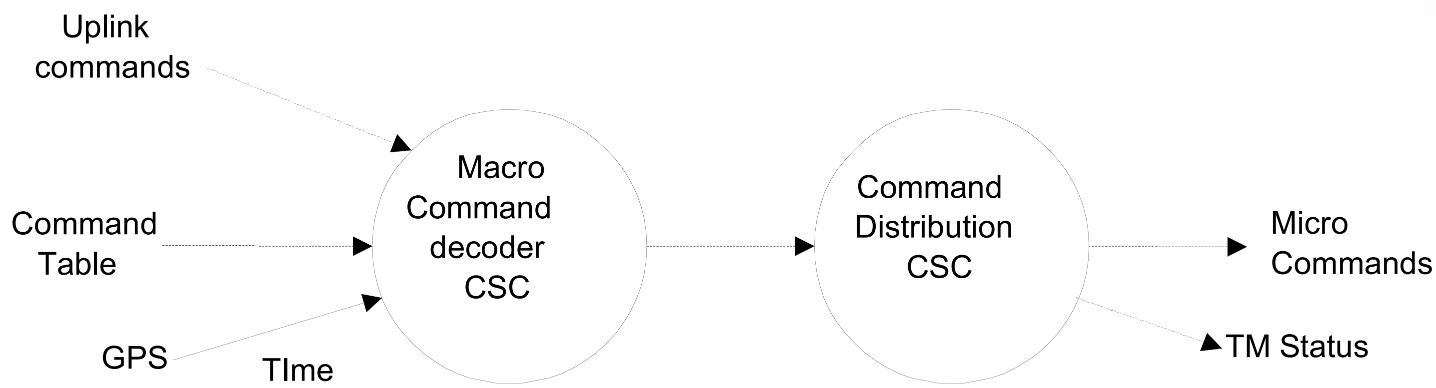
- 1553 Init CSC - The 1553 Registers and Descriptor Block Will Be Initialized. To Process Messages the Remote Terminal Uses Data Stored in Registers and Memory
- 1553 ISR CSC - Reads the Pending Interrupt Register. The Command Word Is Read to Determine Receive or Transmit and Subaddress
- 1553 Transmit CSC - Writes 16 Bit Words From a Transmit Buffer to a Subaddress
- 1553 Receive Handler CSC - Reads 16 Bit Words From Subaddress and Writes Them Into a Buffer
- Each Subaddress Has up to 32 Word Packets With Headers and CRC

GPS CSC



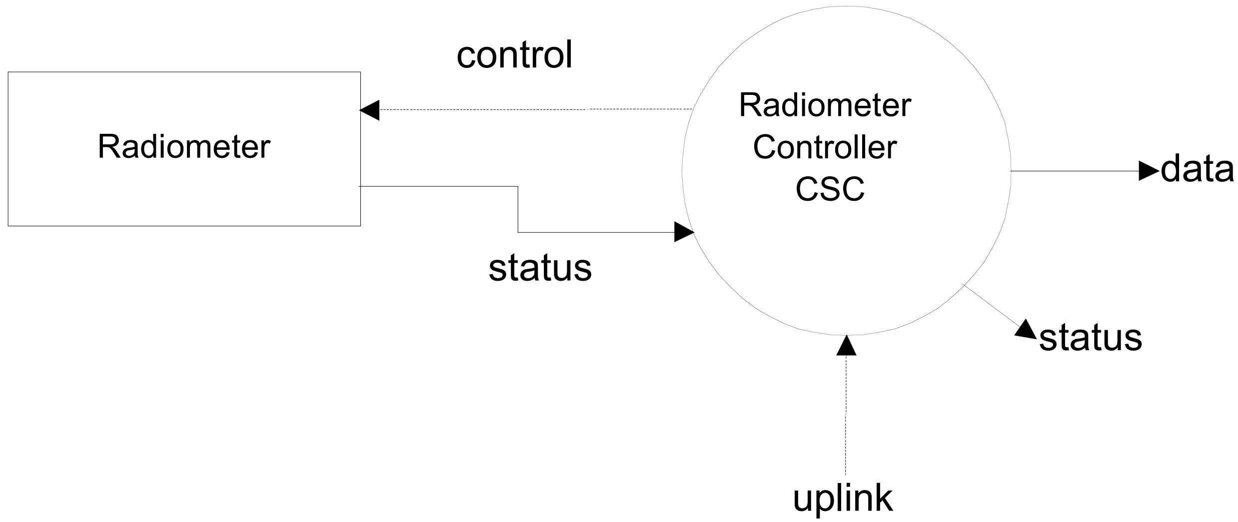
- **GPS Main CSC - Manages Incoming and Outgoing Messages**
- **GPS Frame Validation CSC - Validates the Received Frame by Checking the Fletcher Checksum**
- **GPS Frame Handler CSC - Strips off Header and Checksum; Retrieves Message Data**
- **GPS Frame Formatter - Formats X.25 Data Frame With Header, Message Data, and Checksum**

Command CSC



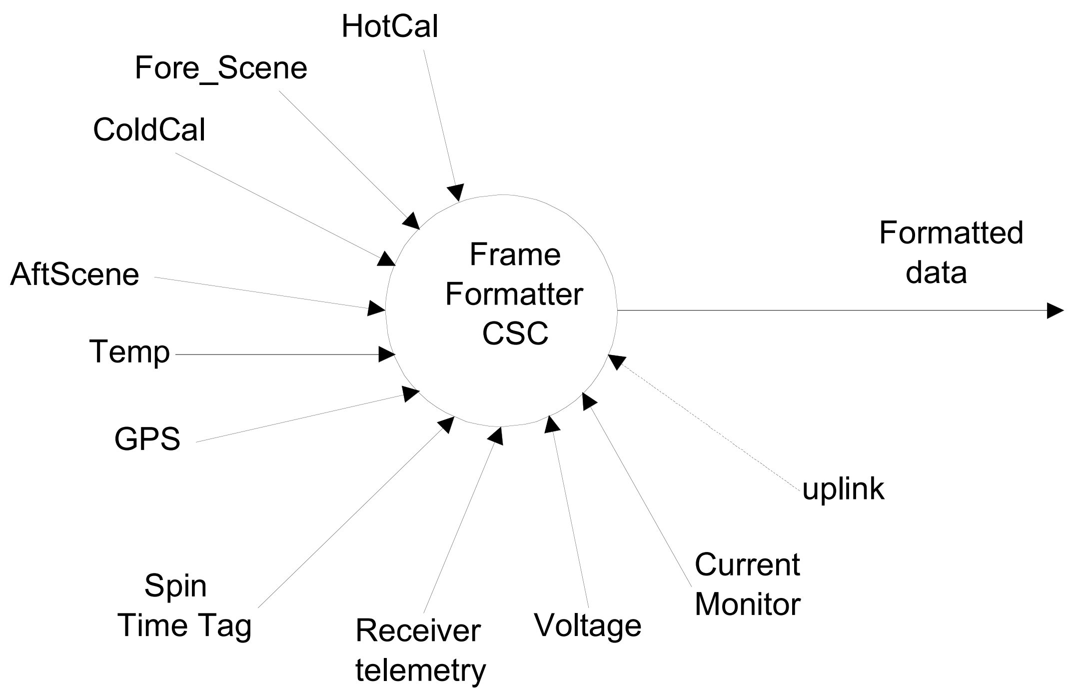
- **Uplink Commands Are Received Over 1553 Bus in Packets up to 32 Words Which Are Validated and Decoded**
- **Macro Command Decoder CSC - A Binary File Is Loaded. The Binary File Is Decoded by an Interpreter and Executed**
- **Command Distribution CSC - The Commands Are Dispatched. Functions in Other CSCs Are Called. Parameters Are Passed**
- **The Uplink Commands Are Generated by a Program on the Ground Which Takes a Script and Builds a Command Table**
- **Micro Command Examples -**
  - **Set GPS Latitude**
  - **Turn on Warm Load Heater**
  - **Reset 1553**

Radiometer Controller CSC



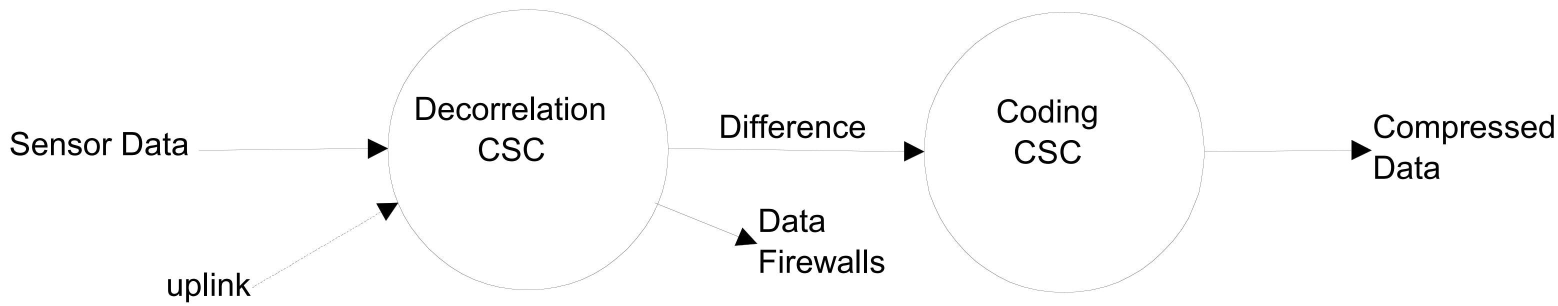
- Setup Registers in the Digital Interface of DEU-1 Thru DEU-5 Via SDLC Stream
- Reads Radiometer Data Along With Register Status, Voltage and Temperature
- Controls Integration Time, Number of Samples, Video Gain, Video Dc Offset, Write/Read Registers
- Repetitive Verification of Parameter Settings in the Receivers, Logging of Errors, and Reprogramming of the Parameters
- Number of Errors Per Spin Recorded and Stored for Downlink

Frame Formatter CSC



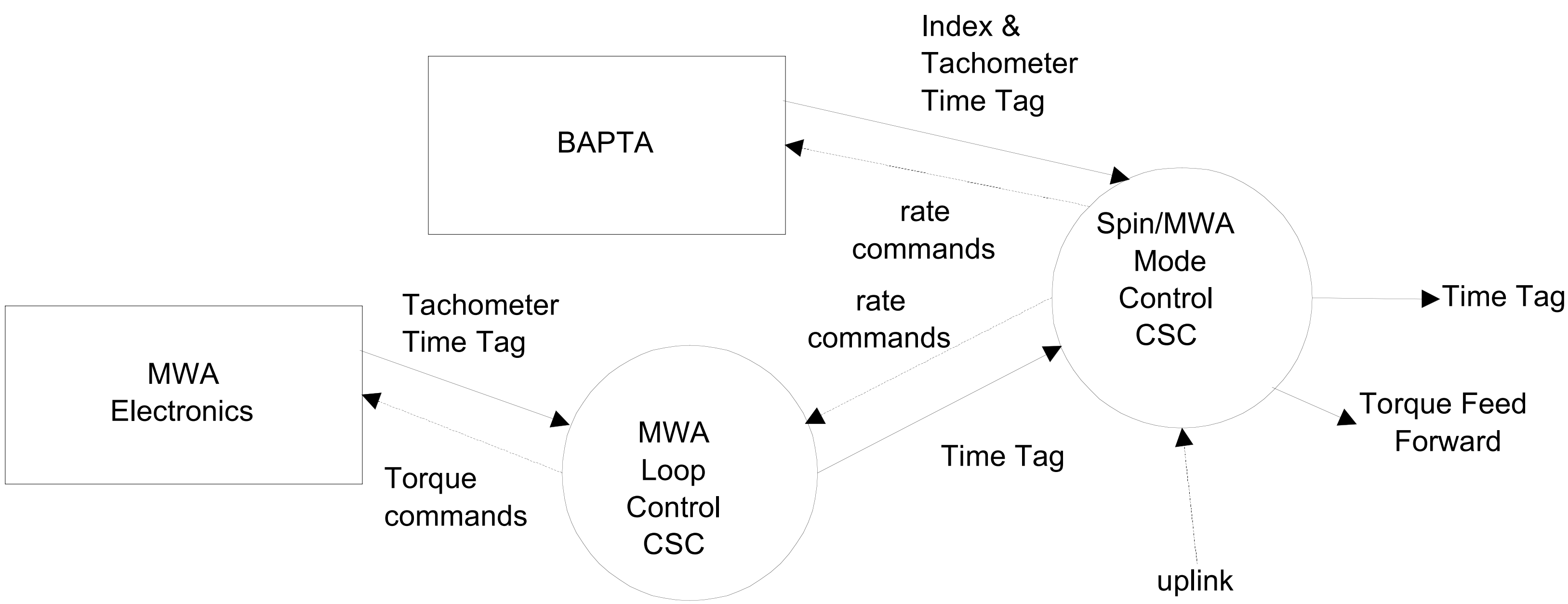
- **Frame Header for Frame Type and Identifier for the Data**
- **Data Is Formatted for 1553**
- **GPS UTC Message Should Be Sent Immediately**
- **Frame Sync, Frame Count, and CRC Added to the Frame**
- **Frame Format Is Uplink Programmable**

Data Compression CSC



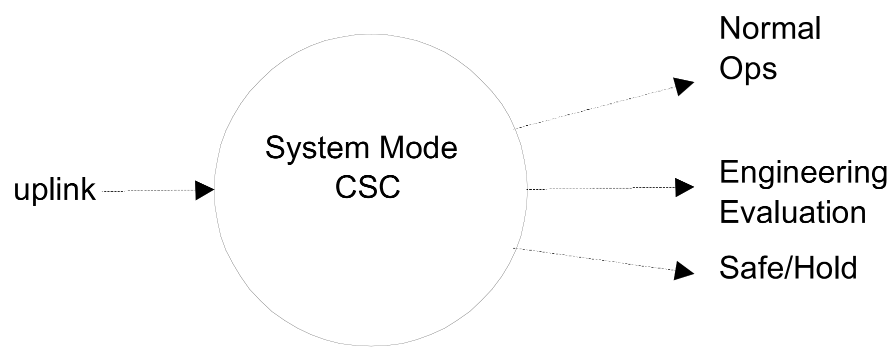
- **Not All of the Mission Data Is Useable Because of Cold Reflector Occlusion. A Programmable Amount of Data Will Be Excised Prior to Compression**
- **Decorrelation CSC - The Difference Between Each Pixel and It's Neighbor Pixel Is Computed for the First Band. For the Next Band, Previous Band Data Is Used As a Reference. A Difference Is Computed With a Predictor Selection and Offset Correction**
- **Data Firewall Limits Error Propagation of Corrupted Data Due to Bit Error**
- **Coding CSC - A Lookup Table Provides a Index Code Word Which Identifies the Difference**

Spin/MWA CSC



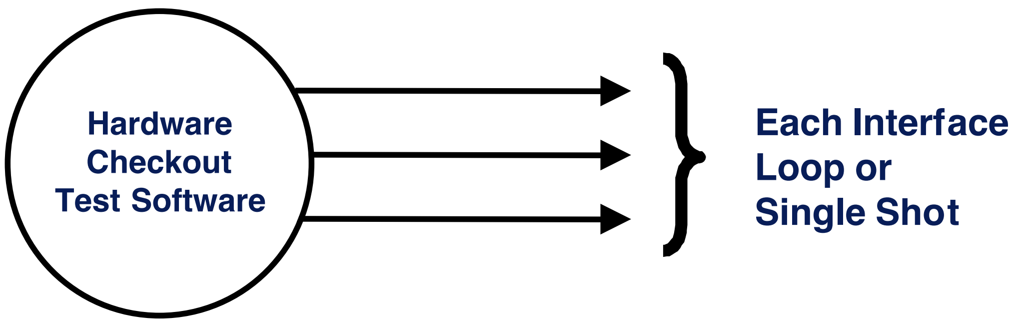
- **Slave Mode - Momentum Wheel Tracks the BAPTA During Spin up and Spin Down**
- **Reverse Slave Mode - BAPTA Follows the MWA Rate Down to Zero**
- **Operational Spin Mode - BAPTA and Momentum Wheel Are Independent**
- **Torque Feed Forward - Message to the Spacecraft of Any Change in Torque**
- **Ground Control of Rate Commands**

System Mode CSC



- Normal Ops - Radiometer Data of Interest With Normal Rates of Status and Support Data
- Engineering Evaluation - All Radiometer Data Sent. Read Registers at Faster Rate; 512 Time Tags Per Spin
- Safe/hold - Turn off Selected Functions but Continue Spinning - Ground Control Takes Over; No Mission Data or Tactical Links

Hardware Checkout Test Software



- **Real-time Software on a Heurikon Baja Board (COTS VME) When Harris Board Not Available.**
- **Test 1553, RS-422, SDLC Interfaces, Torque Control, Ramp Control**
- **Debug of Flight Software**

Source Lines of Code Estimate

Function	est. SLOC	Comments
Hardware Driver CSC	1200	
Command Macro Decode CSC	500	
GPS CSC	500	
Radiometer Control CSC	200	
Data Formatter CSC	500	
Data Compression CSC	500	Algorithm in development
1553 Remote Terminal CSC	200	Use ICM source
Spin/MWA Control CSC	200	
Attitude Determination CSC	0	TBR
System Mode Anomaly CSC	1000	
Hardware Checkout Test Software	2000	
Total SLOC	6800	

Memory Utilization

Description	Size
Code	
Application(4300 x3.8 = 16.3 K)	16.3 K
VxWorks 5.3.1, Kernel, Libraries	200 K
Data	
Application	8K
Data Buffers	506 K
Macro Command Storage	128 K
1553 Storage	3.8 K
Total	862.1 K
Memory Available - 128 MB	
Spare Memory - 99.4 %	
EEPROM Available - 2 MB	
Spare EEPROM - 89.2 %	

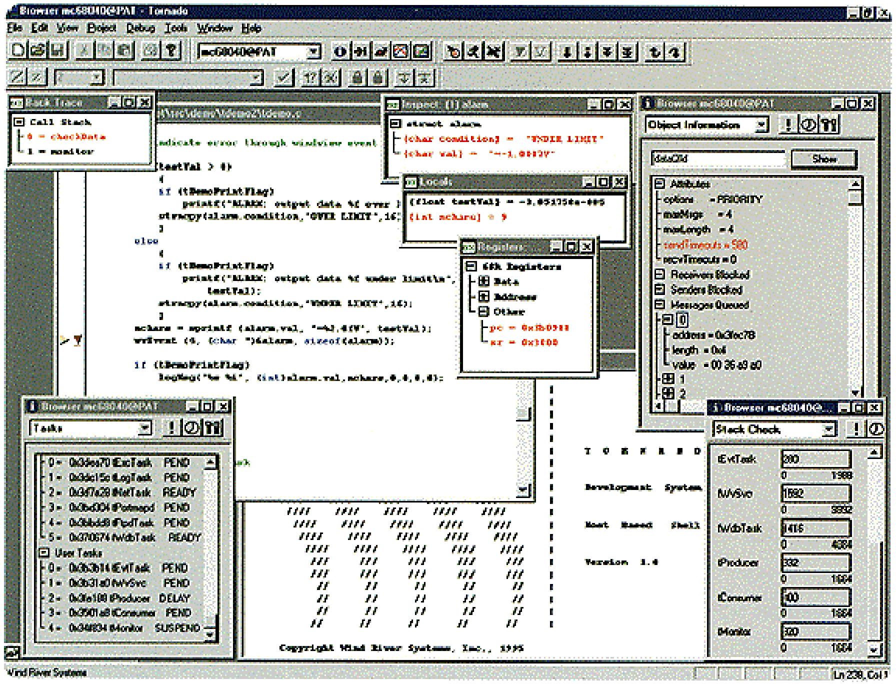
Code in EEPROM is loaded into RAM

CPU Utilization Estimates

Description	inst/sec	% (of 20 MIPS)
Hardware Driver CSC	100 KI/sec	0.5%
Command Macro Decode CSC	110 KI/sec	0.6%
Radiometer CSC	100 KI/sec	0.5%
Data Formatter CSC	1500 KI/sec	7.5%
1553 Remote Terminal CSC	1500 KI/sec	7.5%
Spin/MWA CSC	130 KI/sec	0.7%
System Mode Anomaly CSC	120 KI/sec	0.6%
Compression CSC	1500 KI/sec	7.5%
VxWorks Kernel	3000 KI/sec	15.0%
Total	8060 KI/sec	40.3%

Development Environment

- Vxworks Tornado RTOS (V5.3.1)
  - Debugger
  - Browser
  - C GNU Compiler
  - Host-based Shell Interface
  - Dynamic Linking and Loading of Object Modules
- Windview (Software Logic Analyzer - Displays Interaction of Tasks and ISRs)
- Flight Code Developed on Heurikon Baja Board and the Harris Board
- Payload Test Rack

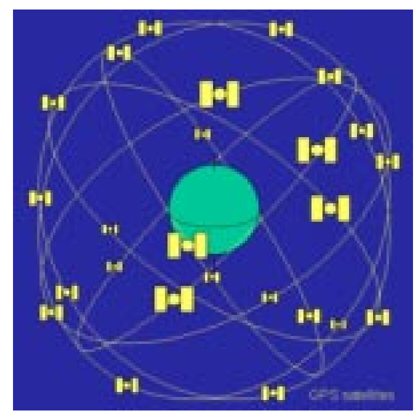


Integration and Test

- All CSUs Tested Stand Alone
- CSUs Integrated With Each CSC
- All CSCs Tested Stand Alone
- All CSCs Integrated Together
- Prototype Integration With DHS
- Integration With RF Subsystem
- Flight Integration

GPS Receiver

Gonyea



GPS Derived Requirements Summary

Specification	Requirement
Position Determination	100 meters 3d 1-sigma (SA on)
Velocity Determination	0.01 meter/sec 3d 1-sigma (SA on)
Timing	UTC-USNO Date & Time Capability 1 PPS Time Tick: 10 microsec accuracy 1-sigma (SA on)
Size	< 150 cu in
Weight	< 10 lb
Power	< 15 Watts
Temperature	-20C°≤Tbaseplate≤+60°C
Radiation	> 20 kRad-Si/SEL Mitigation
Data Interface	Serial RS-422
Antenna	Hemispherical radiation pattern

GPS Receiver Trade Matrix

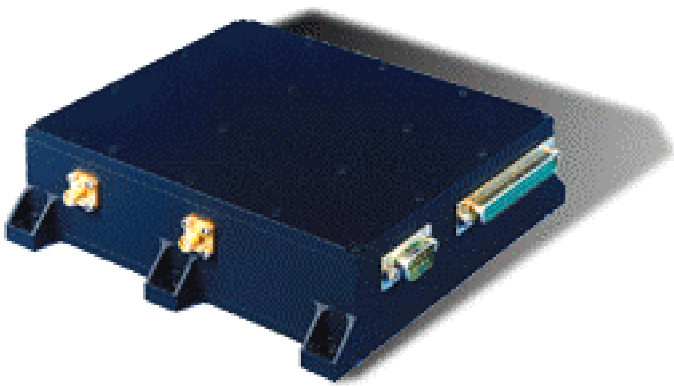
GPS Receiver Options	Requirements	Motorola		Allen Osborne Assoc.	Spectrum Astro
Model		**Monarch**	**Viceroy**	**TurboStar**	**AstroNav**
Frequencies	L1	L1,L2	L1	L1,L2	L1,L2
Codes Utilized	C/A	C/A,P/Y	C/A	C/A,P	C/A,P(Codeless)
# Channels		12 (Options 6-24)	6 - 12	8	Up to 48
# Antennas		1-4 (2 Std. Included)	1 or 2 (Included)	1 (More Optional)	1 (To 4 Opt)
LNA's @ Antennas	Yes	Not Required	If Needed	Yes, if Needed	Yes, if Needed
Position Error (3d, rms) No SA	200m	15m	43m	346m	173m
Time Error (1Sigma) No SA	1 us	100ns (C), 20ns (P)	300-400 ns		<100ns
Position Error (3d, rms) W/SA	200m	15m	173m	346m	173m
Time Error (1Sigma) W/SA	1 us	100ns (C), 20ns (P)	1 us	±100 ns	100ns
Position, Velocity, Time	Yes	Yes	Yes	Yes	Yes
Pseudo-Range, Carrier Phase	Yes	Yes	Optional	Yes	Yes
Attitude	No	No	No	No	Optional
1PPS Output	Yes	Yes	Yes	Yes - 1	Yes - 1 or 2
1PPS - Type	TTL/RS422/485	TTL/ECL	2-RS422	TTL - Single ended	RS422
I/O Interfaces	RS-422	1553B	RS485/422	2 - RS422	2- RS422, 1553
Parts Quality	883B/Commercial	883B	883B/Commercial	Commercial	Commercial
MaxVelocity	0.5 Km/s	Configurable	8 Km/s	60 Km/s	Defer to JPL
Max Acceleration		Configurable	10 m/s2	1 g(Acq)/6 g (Trk)	Defer to JPL
Temp Range	-20 to +60C	-34 to +71C	-20 to +60C	-30 to +60C	0 to 70C (Jason)
Size (LxWxH)		7.98" x 7.45" x 5.52"	6.0" x 5.2" x 1.7"	8.4" x 8.4" x 1.8"	6.0" x 6.0" x 3.5"
Weight		7.5 Lbs	3.4 Lb	5.5-7 Lb	1.76 Lbs
Power		25W	4.8W	9-13W	10 W/5 W
Voltage(s)		20-32 VDC	20-32 VDC	9-36 VDC	28 VDC
Total Dose	20K Rads	100 K Rads	25K Rads	~20-30? K Rads	15 - ?30 K Rads
SEU	Tolerant	<1 Per Year	~1/1-3 Months	(WDT)	(WDT, Mem Scrub)
Latchup	Infrequent Latchup W/ Mitigation	Immune	(WDT,Current Mon) Auto Restart	(WDT,Current Mon) Auto Restart	(WDT,Current Mon) Auto Restart
Previously Built/Flown	Preferred	Yes	Yes	Yes	No
Can Handle 30 RPM Spin?	Necessary	Yes	Yes	Yes	Yes
Advantages		**Extremely High Performance**	**Good Performance, KnownQuantity**	**Higher Performance, Slightly Lower Cost**	**Higher Performance, JPL Technology/Use**
Disadvantages		**Overkill, Extremely HighCost**	**Moderately High Cost**	**Problems with 4 unitsonGFO**	**Has not flown, currently in development**

Note: Position error performance estimates restated for common units of measure, code phase performance only.

Motorola Viceroy GPS Receiver & Oncore Antenna

VICEROY™

GPS Spaceborne Receiver



Navigation Solution Accuracy*

- Autonomous Position (typical): ± 100 meters 2d RMS (SA_{ON})
  ± 25 meters 2d RMS (SA_{OFF})
- Time Offset 1µs (SA_{ON})

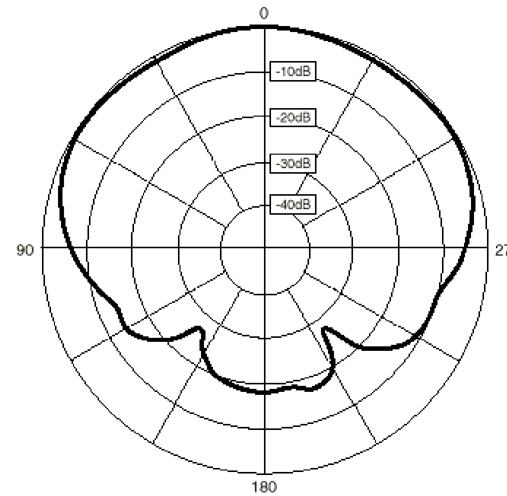
Time-to-First-Fix

- Mean TTFF < 60 sec
- User S/C Ephemeris < 10 km, 10 m/s
- User GPS Clock Error < 1 sec

Orbital Dynamics (typical/spacecraft orbit):**

- Velocity 8,000 m/s
- Acceleration 10 m/s²

Oncore™ Active GPS Antenna



Cross Sectional View

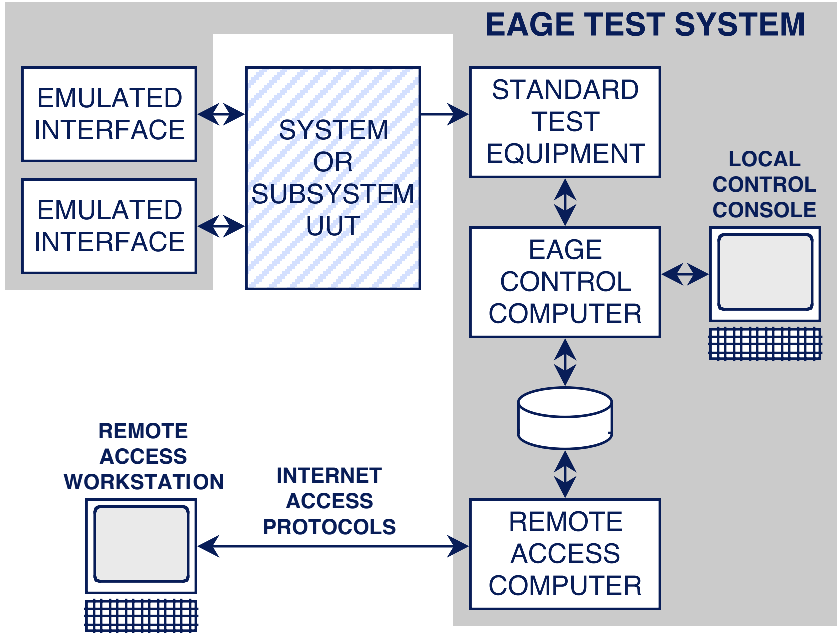
Electrical Characteristics	Power Requirements	• 5 ± 0.5 Vdc 50 mV p-p ripple (maximum)
	Power Consumption	• 20 mA @ 5 Vdc (typical)
Physical Characteristics	Dimensions	• 49.6 L x 43.0 W x 18.0 H mm • 33.3 L x 29.8 W x 8.8 H mm (Substrate w/shield)
	Weight	• < 40 grams (housed assembly, less cable)
	Cable Connector	• 90 degree OSX/MCX (subminiature push on) • BNC • Call for other connector types (SMB, GT5...)
	Antenna to Receiver Interconnection	• Single RG-174U type coaxial cable 6 meters (20 ft.) long (10 dB maximum loss at 1575.42 Mhz) • Single RG-174U type coaxial cable 203 mm (8 in.) long
Environmental Characteristics	Operating Temperature Storage Temperature	• -40°C to +100°C • -40°C to +100°C
	Humidity	• 95% noncondensing +30°C to +60°C
	UV Radiation	• 1200 hrs. @ +63°C w/rain @ 12 min./hr.
	Salt Spray Test	• Spray 5% NaCl solvent at +35°C for 320 hrs.

Electrical Aerospace Ground Equipment

Stuart Nicholson

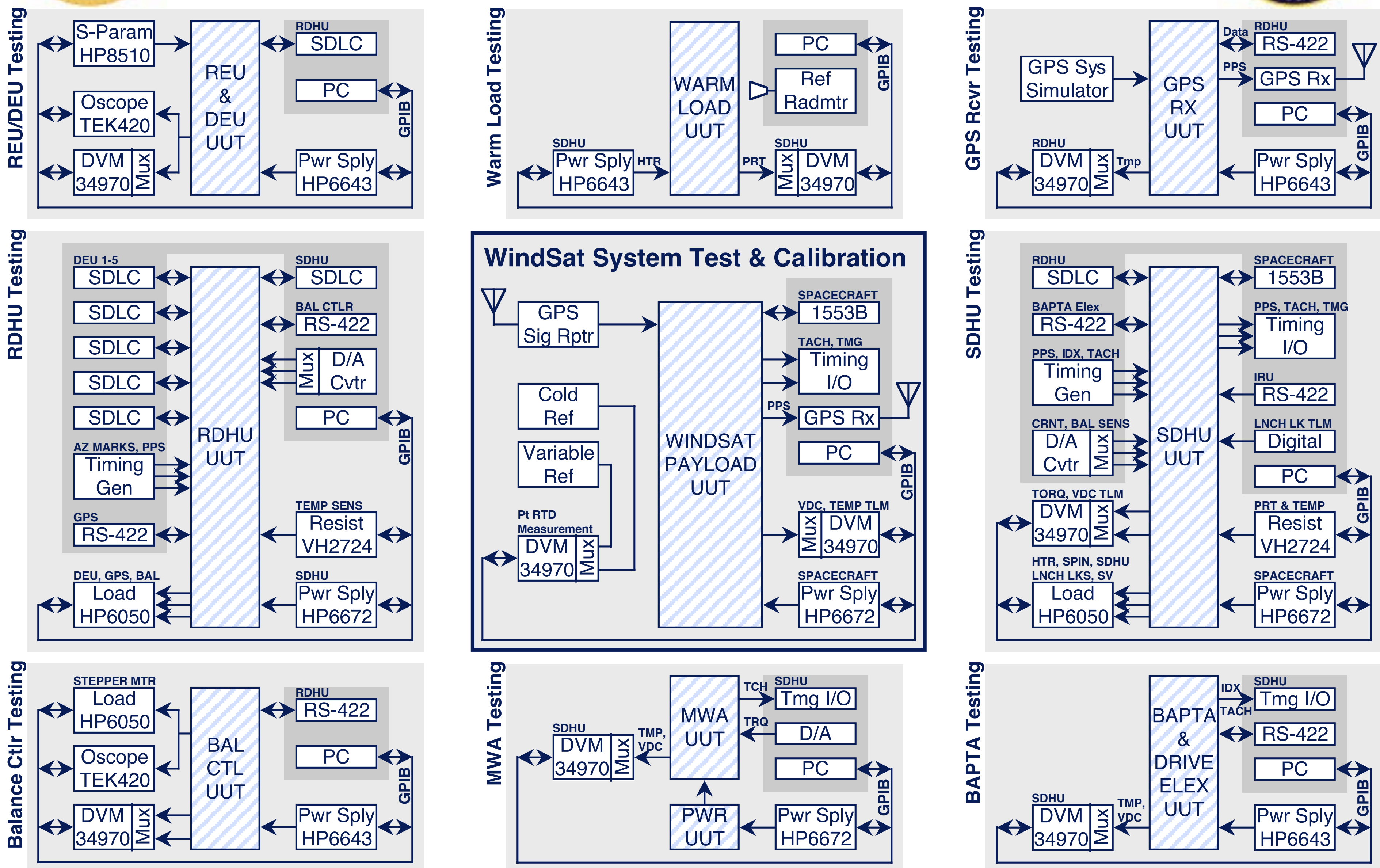
EAGE Architecture

- **Common EAGE Design Addressing:**
  - **System Level Integration and Calibration Testing**
  - **Subsystem Checkout and Acceptance Level Testing**
- **Maximize Use of COTS Test Equipment, Computers, Boards and Software Development Tools**
  - **Select Payload Interfaces Based on Existing Standards**
  - **Utilize Rapid Development High-Level Tools like National Instruments' LabWindows**



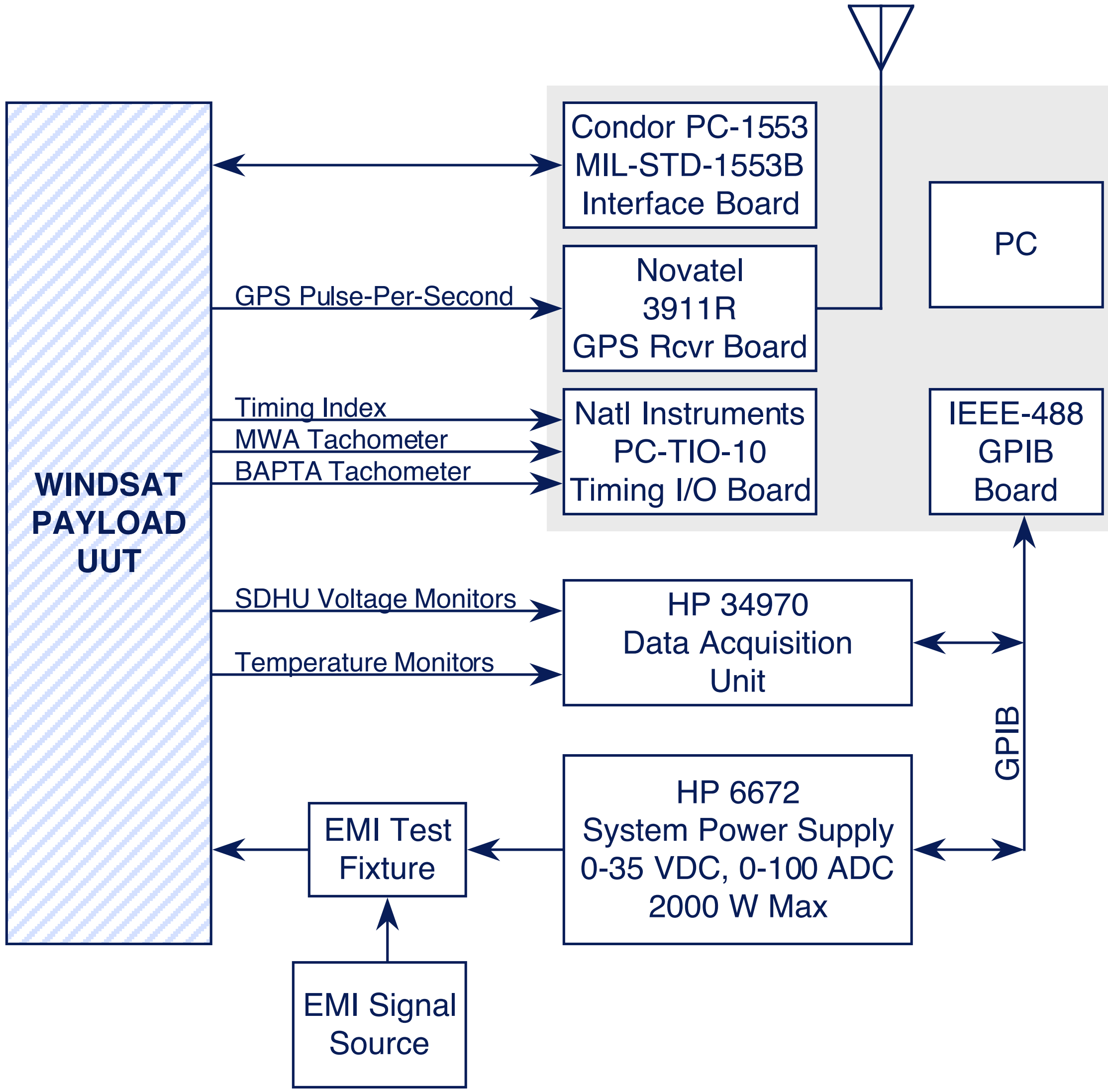
- **Provide Realtime Remote Access to EAGE Test Result Data Using Internet Protocols and Standards**
- **Post-Processing Utilities Directly Applicable in Mission Operations**
- **Command and Telemetry Databases Developed for EAGE will be Transitioned Directly to Mission Operations**

EAGE Configurations



EAGE Spacecraft Interface Emulation

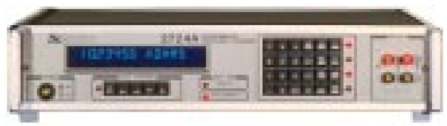
- **MIL-STD-1553B Interface Emulates Spacecraft Data Interface**
- **EAGE Verifies Timing and Electrical Levels of WindSat-Provided Interface Signals**
- **Independent GPS Receiver Verifies Accuracy of GPS Pulse-Per-Second Signal**
- **Data Acquisition Unit Verifies and Calibrates Telemetry WindSat Provides to Spacecraft**
- **Programmable Power Supply Emulates Spacecraft EPS Subsystem**
- **EMI Testing of Power Interface Accommodated**

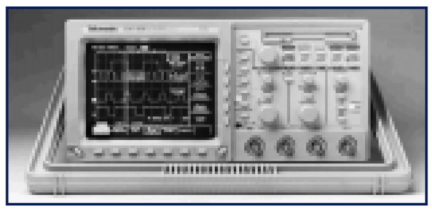


EAGE Electrical Design

Laboratory Test Equipment

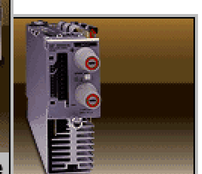

HP 34970A data acquisition/switch unit





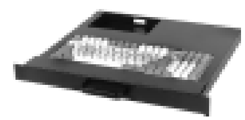

HP 6671A System Power Supply


HP 6050A Electronic Load Mainframe


HP 60501A/HP 60503B Electronic Load Module

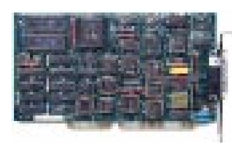
Industrial Computer Components

Redundant Cooling
Redundant Power
Redundant Disks
Passive Backplanes

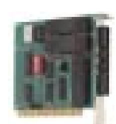


COTS Computer Boards

MIL-STD-1553B
BC, RT, Monitor

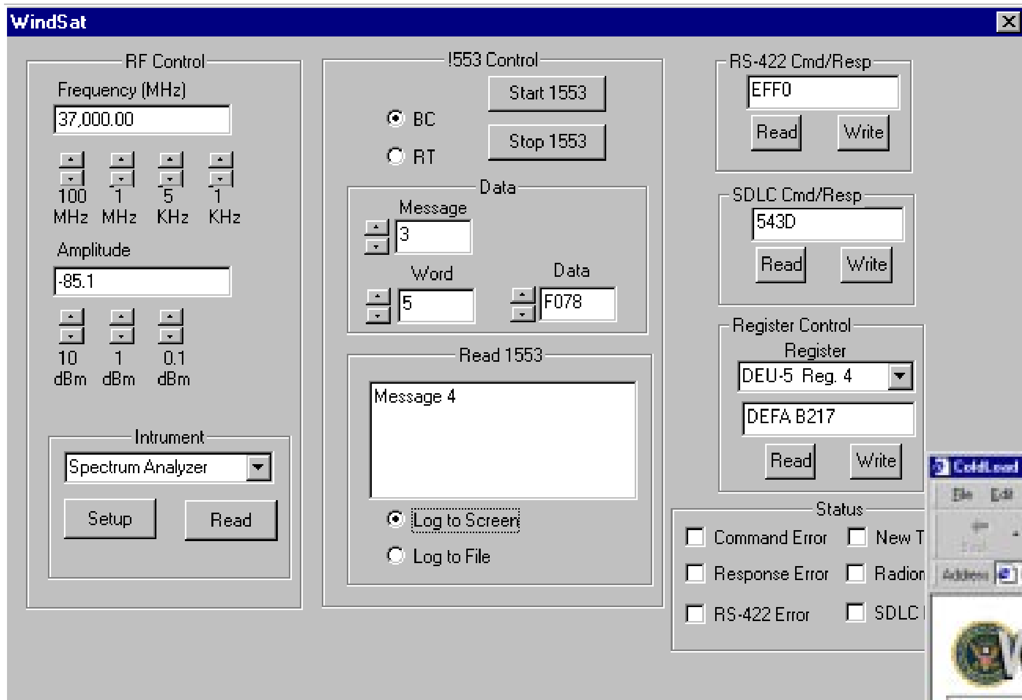


SDLC and RS-422
Serial Cards

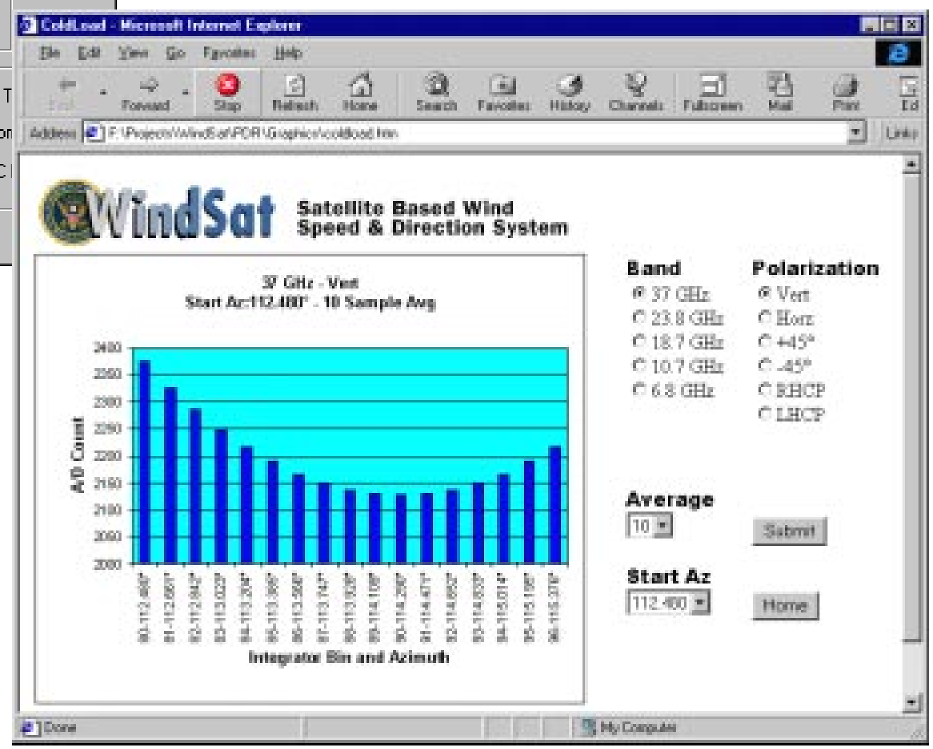


Timing, Digital,
and Analog I/O

EAGE User Interfaces

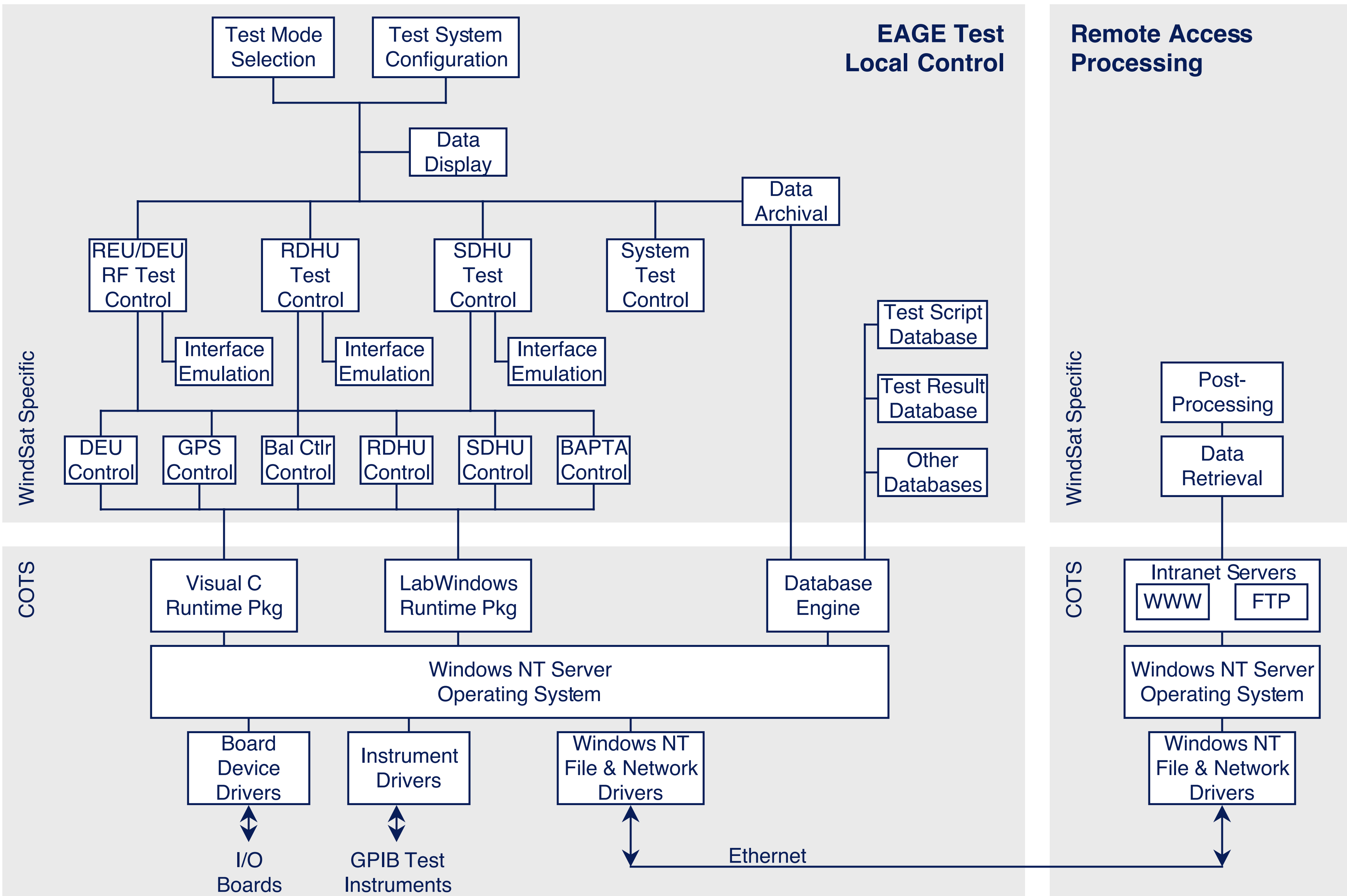


- **Local Control of WindSat Payload and Data Logging Computer**
- **Implemented with Visual C and LabWindows**



- **Remote Access of Test Data Using Standard Internet Protocols and Tools**
- **Implemented with COTS FTP and WWW Server Services**
- **Post-Processing Based on CGI Scripts Using Languages Such As PERL**

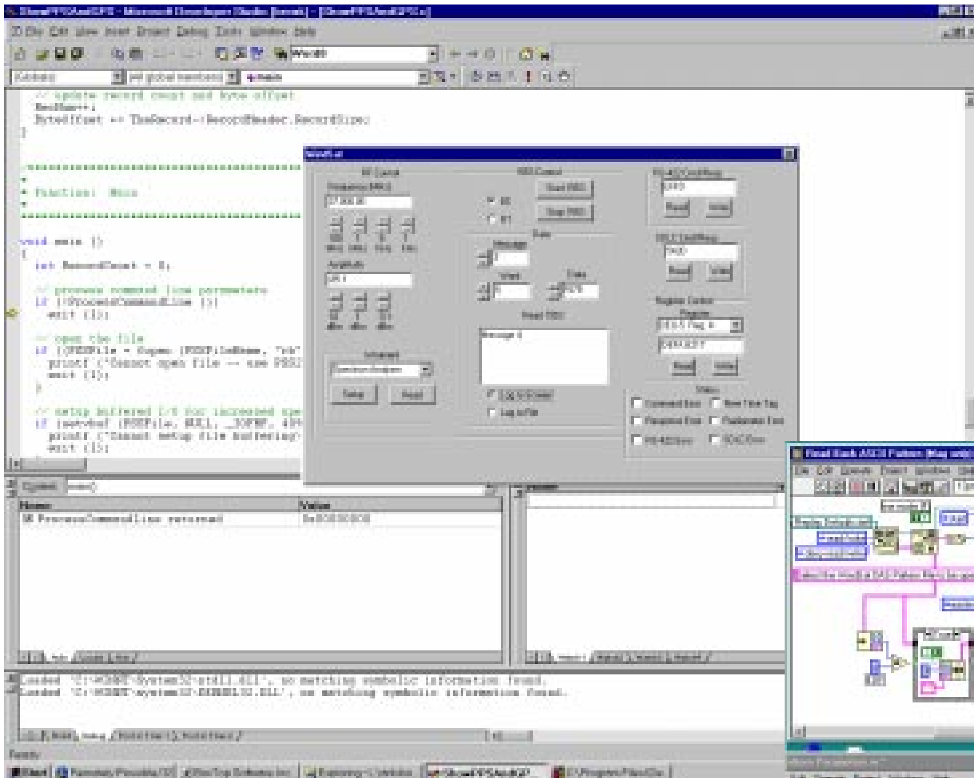
EAGE Software Architecture



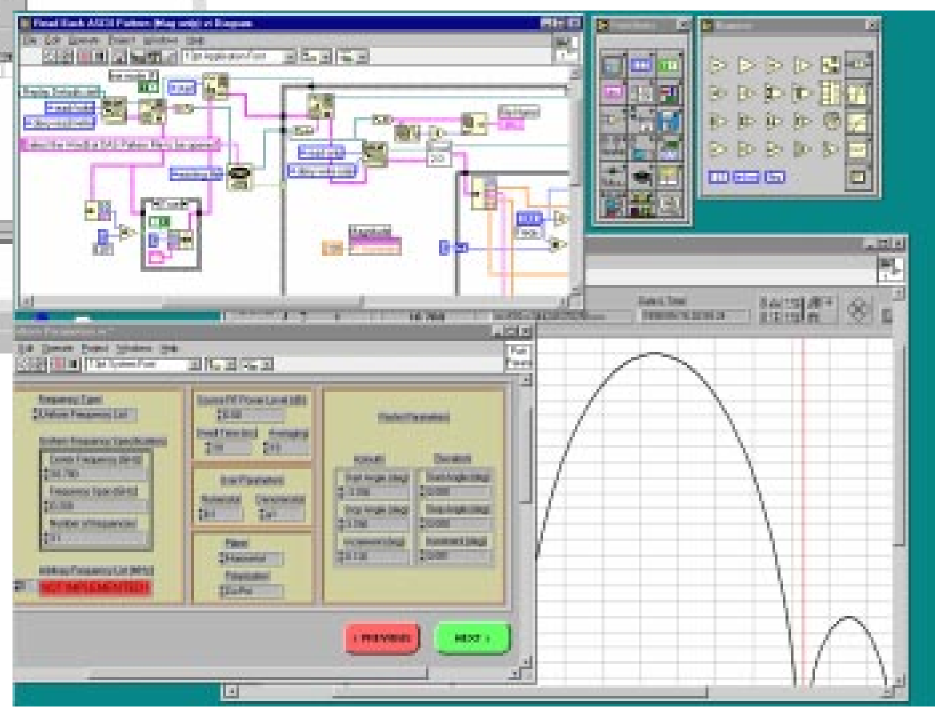
980610_WS_PRD_EAGE.7

EAGE Software Development

- Microsoft Visual Studio Widely Used and Provides Excellent Debugging Tools
- Many Inexpensive 3rd Party Software Libraries Available



- National Instruments LabView and LabWindows Provides Rapid Development Tool
- Existing Driver Modules for Many Test Instruments



EAGE and Mission Operations Databases

- Macro and Micro Commands and Scripts
- Telemetry Decommutation Tables
  - Payload Housekeeping Data
  - Radiometer Support Housekeeping
  - Radiometer Data
- Engineering Units Conversion
- Test Pass/Fail Criteria
- Calibration Data
  - Radiometer Transfer Function
  - PRT and Thermistor Curves
  - Analog Telemetry Curves
- Critical Telemetry Items, Alarm Limits
- Ephemeris Archive
- Flight Software Archive
  - Engineering Development Library
  - Released Builds
- Technical Directives

EAGE Procurement Status

- **System Architecture Definition Complete**
- **Detailed Hardware Design Underway**
- **Software Architecture Definition Underway**
- **Initial Utilization Oct 98 For DHS Unit Integration and Checkout**

Qty	*Vendor*	*Part Number*	*Description*	*Status*
Laboratory Test Equipment				
2	HP	34970A	Data AcquisitionSwitch Unit	On Order
4	HP	34904A	4 x 8 Two-Wire Switch Matrix	On Order
2	HP	34901A	20-Channel Armature Multiplexer	On Order
1	HP	6672A	System Power Supply	On Order
2	HP	6643A	System Power Supply	On Order
1	HP	6050A	Electronic Load Mainframe	On Order
6	HP	60503A	Electronic Load Modules	On Order
1	Valhalla	2724A	Precision Resistance Calibrator	On Order
1	Tektronix	TDS 360, Opt 14	Digital Storage Oscilloscope	On Order
1			GPS Satellite System Simulator	NRL Eqpt
Software				
2	Microsoft		Windows NT Server	On Order
1	National Instruments		Labview 5.0 Software	On Order
1	National Instruments		LabWindows Software	On Order
1	Condor Engineering, Inc	BusTools/1554	BC Monitoring multi-function software	On Order
Miscellaneous				
4	National Instruments	763061-01	GPIB cable, 1 meter	On Order
4	National Instruments	763061-02	GPIB cable, 2 meter	On Order
1	American Power Conversions	SU2200RM3U	Rackmount Uninterruptible Power Supply	On Order
1			Rack Enclosure	Not Chosen
			Ethernet Cabling	Not Chosen
			Connectors	Not Chosen
Computer Components				
1	Appro	50898-TM98	Rackmount Computer, Including 2 Dual Pentium Pro Computer Boards, Backplane, Monitor, Disc Drives, Tape	On Order
1	Appro	APRE-4085HT	RAID Disc Drive Array Chassis	On Order
2	National Instruments	776452-01	PC-TIO-10 Timing Board	On Order
1	National Instruments	777073-51	IEEE-488 Board, software, cable	On Order
2	National Instruments	777565-01	PCI-6810 Serial Data Analyzer, Win NT	On Order
2	Sealevel Systems	4011	2-channel High Speed Serial Board	On Order
1	Condor Engineering, Inc	PC-1553	ISA Multi-function 1553B	On Order
1	NovaTel	3911R	GPS Receiver Card	On Order
			D/A Convert Card	Not Chosen
			KVM Switch	Not Chosen

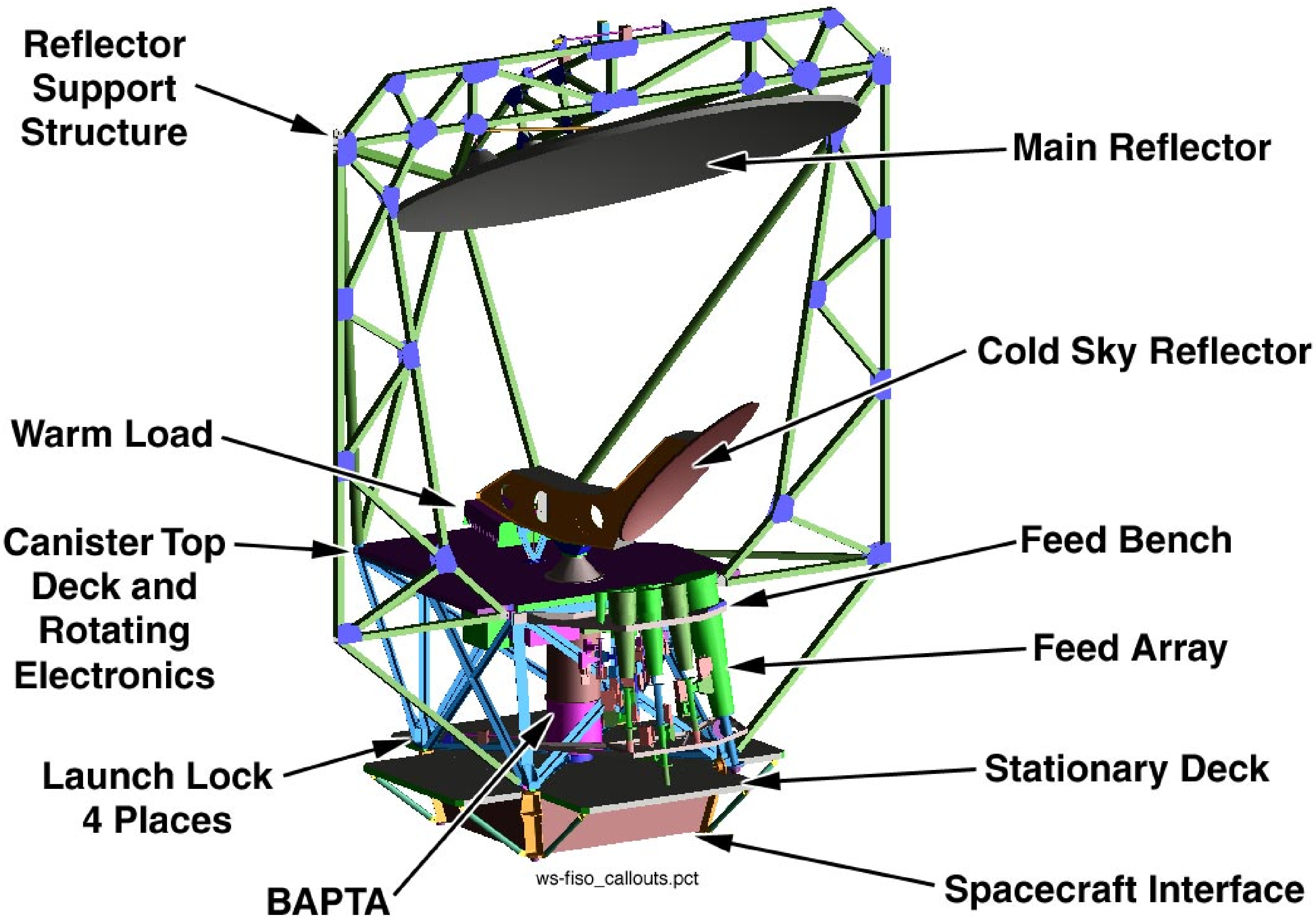
Mechanical Systems

Bill Purdy

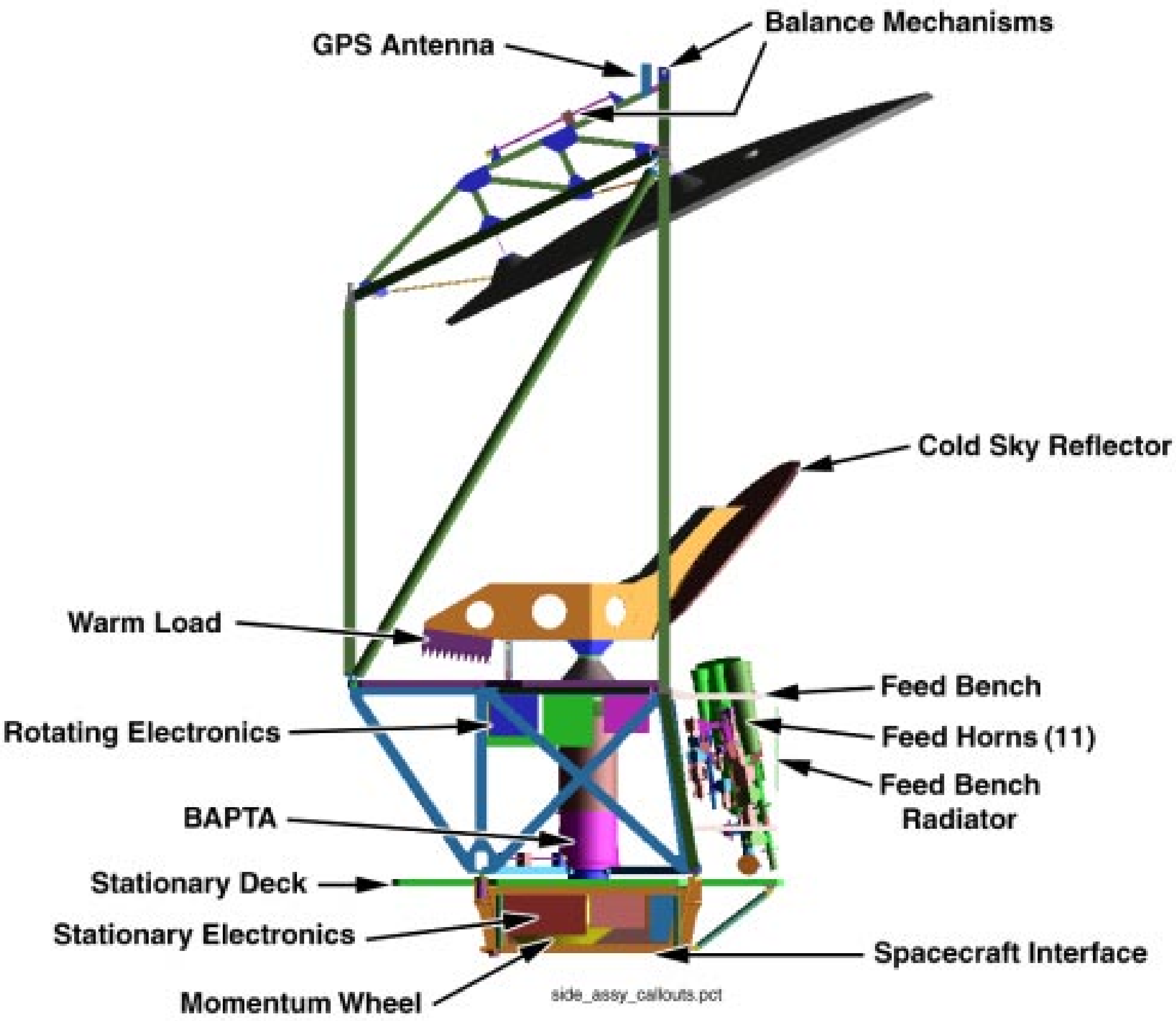
Mechanical Systems Agenda

- Mechanical Systems Overview — Bill Purdy
- Reflector, Feed Bench, Alignment Plan Presented in Antenna Subsystem
- Structure, Analysis and Packaging — Jim Pontius
- Mechanisms — Steve Koss
- Thermal Control — Mark Cheung
- Pointing Determination & Control — Mike Mook

Mechanical Systems Overview Drawings

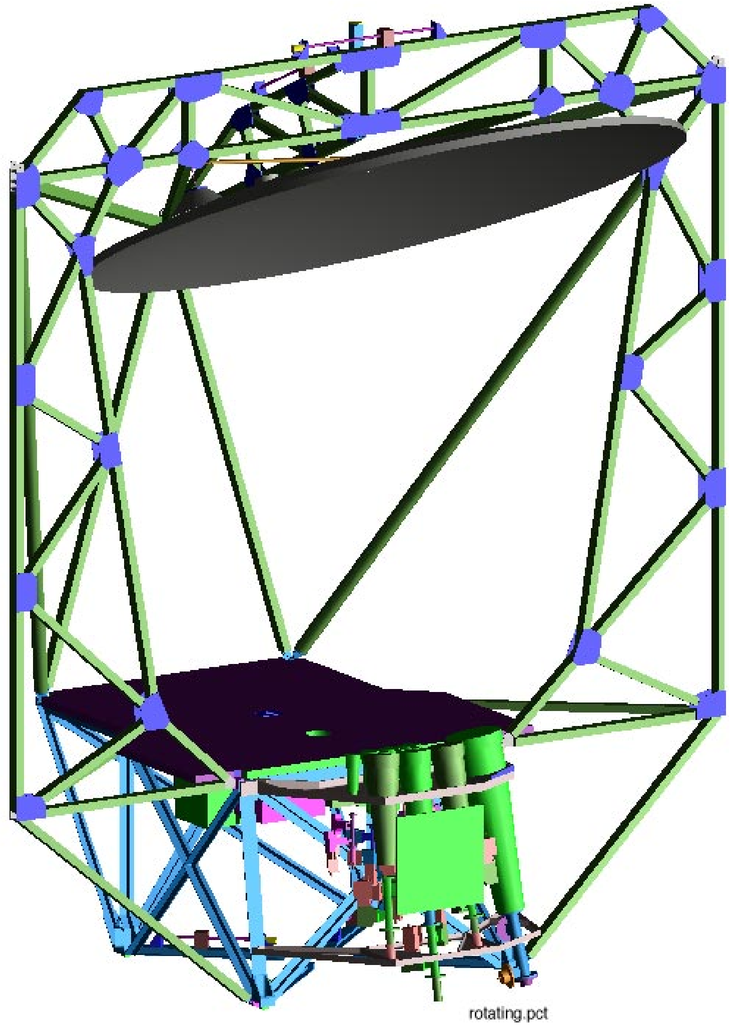


Mechanical Systems Overview Drawings



Mechanical Systems
Rotating vs Stationary

Stationary



Rotating

Mechanical Systems - Components List

Mechanical Systems ······ **Antenna**

Antenna
- Reflector – W. Pogue
- Feed Bench – S. Cottle

Pointing Determination & Control
M. Mook
- Momentum Wheel
- Wheel & BAPTA Controls
- Pointing Error Budgets

Thermal
M. Cheung
- Truss
- Canister
- Feed Bench

Packaging
A. Feerst
- Component Placement
- Structure Interface
- Thermal Interface

Mechanisms
S. Koss
- BAPTA
- Launch Locks
- Balance Mechanisms

Structure
J. Pontius
- Canister
- Structural Analysis
- Thermal Deformation Analysis
- Reflector Support

Feed Bench
S. Cottle
- Structure
- Adjustment Mechanisms

Mechanical System Design Drivers (1 of 2)

- Pointing Knowledge
- Thermal Stability
  - .005°C/sec; ± 2°C/orbit
- Heat Rejection
- Total Angular Momentum
  - Limited by Available Low Cost Momentum Wheel
- Slip Ring Life
- RF - Mechanical Integrated Antenna Design

Mechanical System Design Drivers (2 of 2)

- **Environments:**
  - **Loads, Vibration, Acoustic, Shock & Thermal System Requirements Previously Presented**

- **Changes From SRR:**
  - **Evolving Understanding of Spacecraft Structural Interface**
  - **Titan 2 Launch Vehicle**
  - **Momentum Wheel**
  - **Cannot Preclude Integration of SMEI**

Mechanical Systems Trades Made (1 of 3)

- Install All Rotating Payload Boxes on Canister Top Deck
  - Heat Rejection Keeps Warm Load Warm & Stable
  - Sufficient Radiator Area
  - Good Thermal Stability
  - Good Electronic Box Packaging

- Feed Bench Implementation
  - LNA's Directly Mounted to Feeds
  - Non Cantilevered Feed Mount
  - Micro Heat Pipe Implementation (Magic Sticks)
  - Best Balance of Thermal, RF & Mechanical Needs

- Payload Has Momentum Cancellation
  - Cleaner Interface
  - Low Cost Wheel Available From MSX Program
  - Reduces Bus Customization

Mechanical Systems Trades Made (2 of 3)

- Structure
  - Composite vs Aluminum
    - Aluminum Chosen for Canister and Stationary Structure
    - Low CTE High Stiffness Composite Chosen for Truss Primarily to Keep Angular Momentum Low
    - Interface Loads at Nominal 38” Diameter of Most RSD Catalog Spacecraft
      - Minimize Impact to Spacecraft
      - Less Efficient Structure Than Larger Diameter

Mechanical Systems Trades Made (3 of 3)

- Deployable Reflector?
  - Deployable Reflector Reduces Height 4’ to 6’
  - Deployment Mechanism System $1M to $2M Cost Increase
  - Non Deployed Reflector Improves Pointing Knowledge
  - Non Deployed Reflector Fits Launch Vehicle Envelope
  - Selected Non Deployed Reflector

Structure Subsystem

Jim Pontius

Derived Requirements

- 205,000 Lb-in^2 (60 Kg-m^2) Rotating Section I_{zz} Based on Inertia Wheel Capability
- Instrument Mass Requirement Pending Spacecraft Selection
  - IMDC Study Indicates Large Mass Margin With Titan II
- Instrument 1 G Bending Moment Pending Spacecraft Selection
- Rotating Section C.G. Location Balanced on BAPTA Spin Axis
- "Adaptable" and "Simple" ~38" Diameter Interface With Spacecraft
- 20 Hz Lateral, 40 Hz Axial Minimum Frequency
- Structure Survival Temperatures: -50^{o}C to 70^{o}C
- Distortion & Pointing For Transient Conditions:
  - EIA: 0.015^o
  - SAA: 0.015^o
  - PRA: 0.015^o
  - Defocus: 0.070"

Derived Requirements: Test

- General Criteria: The WindSat Payload Structure Is Considered a Proto-Flight Unit
- Intent Is That Most, If Not All, of the Major Structural Flight Components Will Be Proof Test Tested to 1.15 x Design Limit Loads And/or Flight + 3 dB Levels. All Bonded Joints Will Be Proof Tested to 1.15 x Design Limit Loads
- All Flight Ground Handling Hard Points Shall Be Proof Tested to 2.00 x Design Limit Loads
- All Mechanical Aerospace Ground Handling Equipment (MAGE) Shall Be Proof Tested to 2.00 x Design Limit Loads
- Positive Margins of Safety For All Components
- Enhanced Bread Board (EBB) Structures Will Not Have to Meet These Requirements, However, They Should Be Applied Wherever Practical

Loads Derivation (1 of 2)

- Axial Load Factors Taken Directly From Launch Vehicle User Manual
- Lateral and Rotational Load Factors Derived From:
  - 5 Cycle Transient Basedrive Approach to Envelope Interface Levels for EELV, Athena, and Titan Launch Vehicles
  - Estimates Liftoff, Engine Cutoff, and Staging Events for Various Launch Vehicles
  - .5 G Transient Applied at Payload Separation Plane for 5 Sinusoidal Cycles, Tuned to Payload Fundamental Bending Frequencies
  - 1.5% Modal Damping (C/C_{crit}) Assumed
  - Detailed Instrument Finite Element Model (FEM) Coupled to Beam Model of Notional S/C Tuned to 25 Hz
  - Satellite C.G. Accels Limited to User Manual Envelopes
- WindSat Instrument Design Load Factors:

Axial (G)	Lateral (G)	Rotational About C.G. (Rad/sec^2)
+10.0 / -2.0	+ / - 4.5	+ / - 39.0

- Will Be Compared With Coupled Loads Predictions When Available

Loads Derivation (2 of 2)

- Component Design Loads Use Mass Acceleration Curve, Single Axis
- Random Vibration Environments Derived From Enveloped Launch Vehicle User Manual Specifications
- Acoustic Vibration Environments Derived From Enveloped Launch Vehicle User Manual Specifications
- Shock Environments Derived From Enveloped Launch Vehicle User Manual Specifications
- Ascent Pressure Environments Derived From Enveloped Launch Vehicle User Manual Specifications
- Ground Handling Loads in Accordance With EWR127-1, Otherwise Use 1.7g Vertical, 0.5 G Lateral
- Transportation Loading Will Be Enveloped by Design Loads

Analysis Factors (1 of 2)

Factors of Safety (FOS):

Flight Structure W/Proof Test FOS

Yield FOS	1.25
Local Buckling	
(Panels, Crippling)	1.25
Ultimate FOS	1.40
Overall Stability	
(No Collapse at Ultimate)	1.40
Fittings	
(Combined With Yield or Ultimate;	
Single Point Failure Only)	1.15
Gapping	
(No Gapping at Test Limit Load)	1.15
Fatigue (Lifetimes)	4.00
Bonded Joint Adhesive Yield	1.15
Bonded Joint Adhesive Ultimate	1.50
Finite Element Model Uncertainty Factor	1.00
Material Uncertainty Factor (Composites)	1.00

Flight Structure W/O Proof Test FOS

Yield FOS	1.60
Local Buckling	
(Panels, Crippling)	1.60
Ultimate FOS	2.00
Overall Stability	
(No Collapse at Ultimate)	2.00
Fittings	
(Combined With Yield or Ultimate;	
Single Point Failure Only)	1.15
Gapping	
(No Gapping at Test Limit Load)	1.15
Fatigue (Lifetimes)	4.00
Bonded Joint Adhesive Yield	N/A
Bonded Joint Adhesive Ultimate	N/A
Finite Element Model Uncertainty Factor	1.00
Material Uncertainty Factor (Composites)	1.00

Analysis Factors (2 of 2)

Flight Structure Ground Handling Hardpoint FOS

Same as Flight Structure w/proof test FOS

MAGE FOS (& Will Comply w/EWR127-1)

Yield FOS	3.00
Local Buckling (Panels, Crippling)	3.00
Ultimate FOS	5.00
Overall Stability (No Collapse at Ultimate)	5.00
Fittings (Combined With Yield or Ultimate; Single Point Failure Only)	1.15
Gapping (No Gapping at Proof Load)	2.00
Finite Element Model Uncertainty Factor	1.00

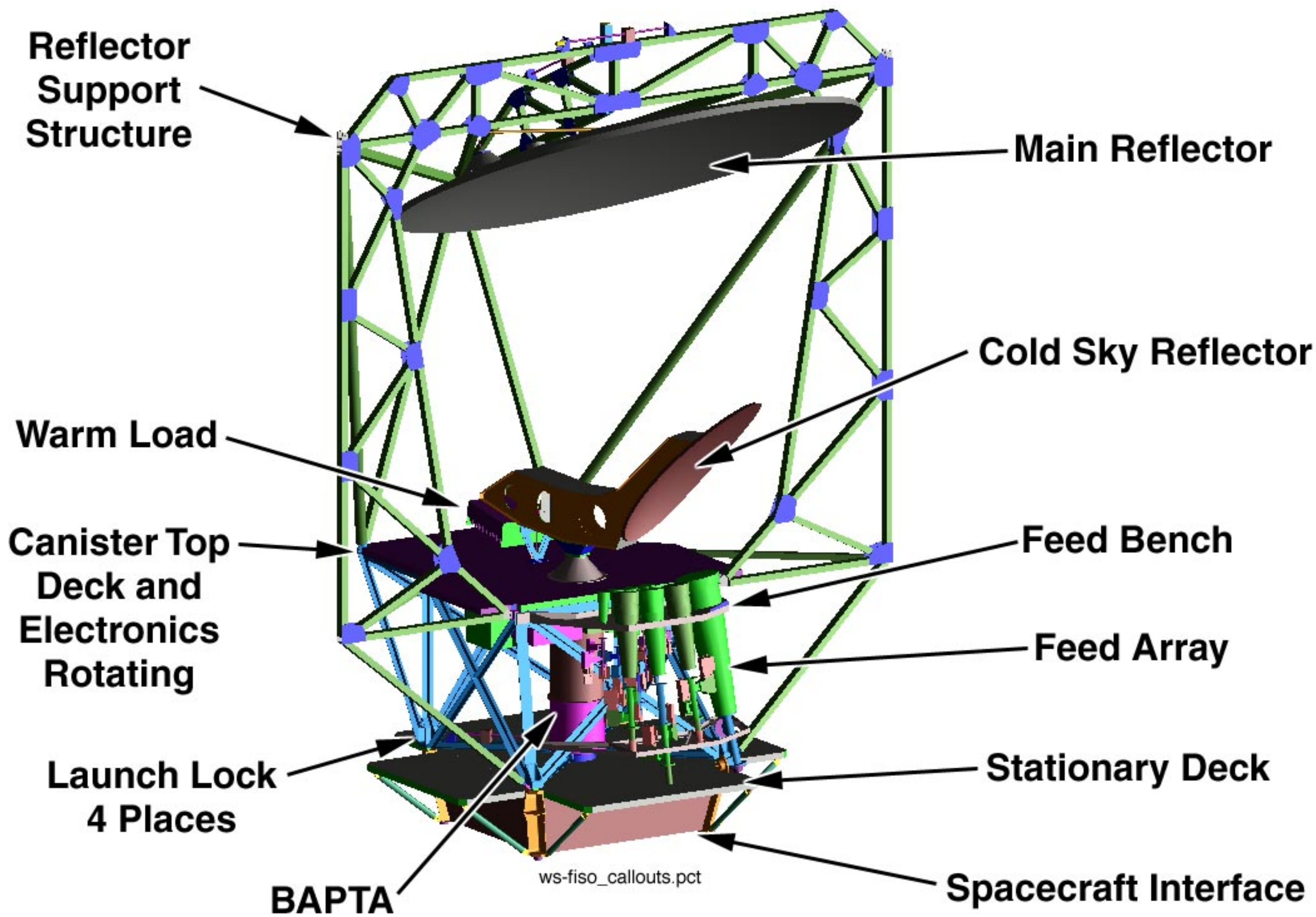
Requirement Is For Positive Margin of Safety (M.S.):

M.S. = Allowable Load/(FOS x Limit Load) - 1

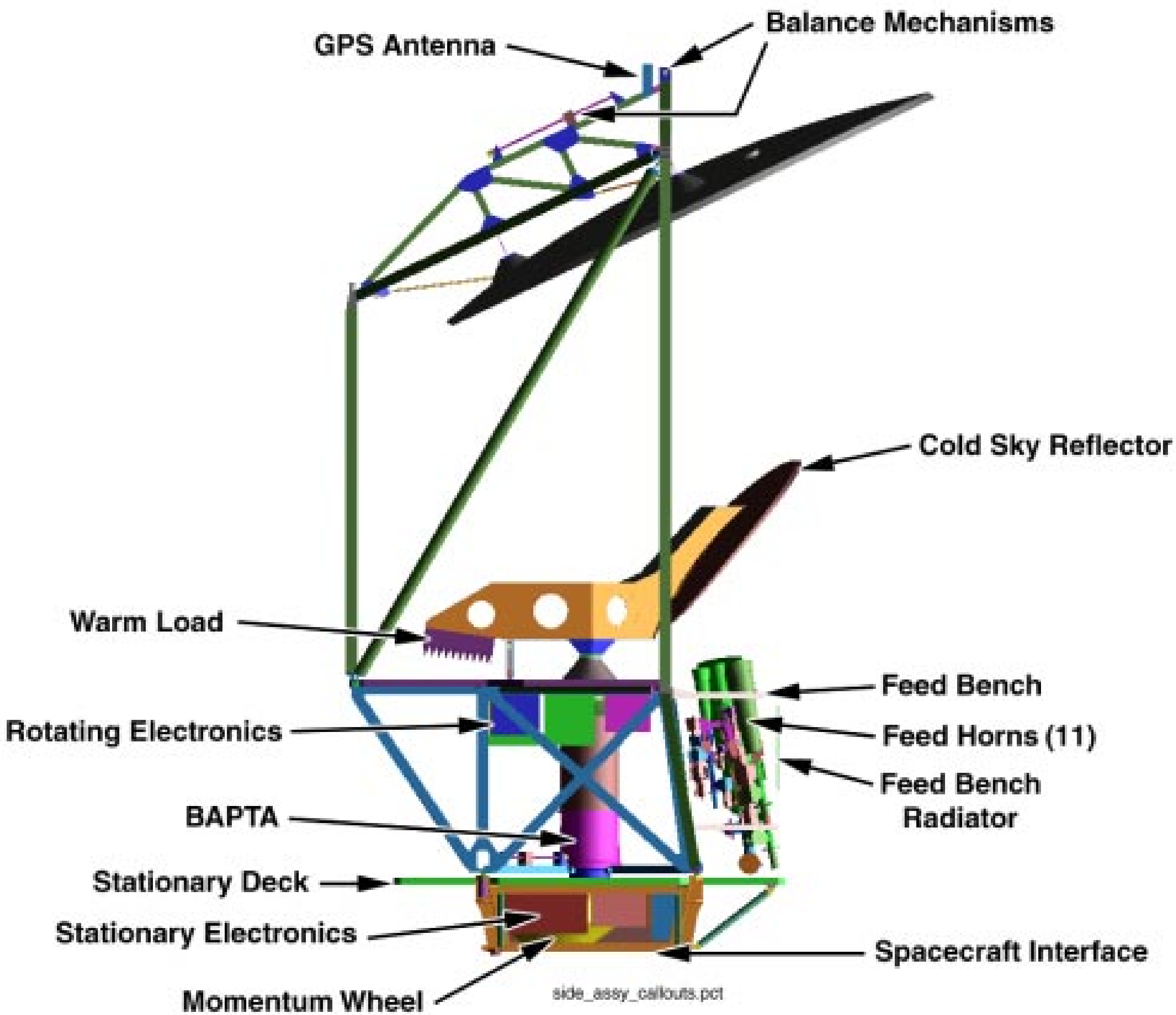
Structural Description

- Approximately 10.5 Ft Tall, 8.25 Ft Wide, 6.25 Ft Deep
- 645 Lb Instrument Weight (Including 20% Contingency)
- C.G. Approximately 35" Above S/C Interface Plane
- Four Point Hard Mount to S/C
- Reflector Support Structural Elements Consist Of:
  - M55J/954-3 Graphite / Cyanate Ester Composite
  - 1.0" x 1.0" x .060"; 1.5" x 1.0" x .060"; 1.5" x 1.5" x .060"; and 2.5" Dia x .060" Composite Tubes
  - .080" Thick Composite Gusset Plates
  - Titanium 6AL-4V Tube Fittings and Reflector Flexures
- Canister and Stationary Structural Elements Consist Of:
  - 2.00" Thick Aluminum Honeycomb Benches With Delron Inserts
    - .020" 7075-T73 Facesheets
    - 5052 Al Honeycomb Core, 2.0 Lb/ft^3, 1/4" Cell Size
  - 7075-T7351 Machined Fittings and Frames

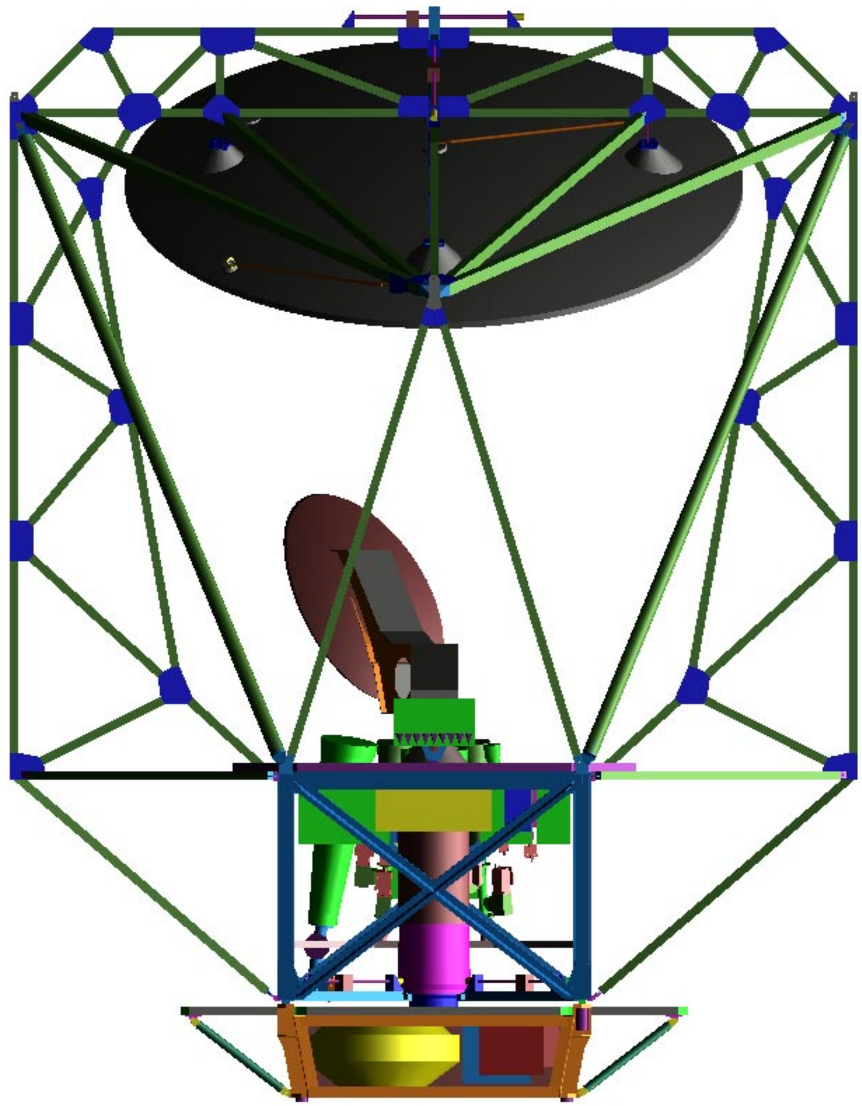
Payload Isometric



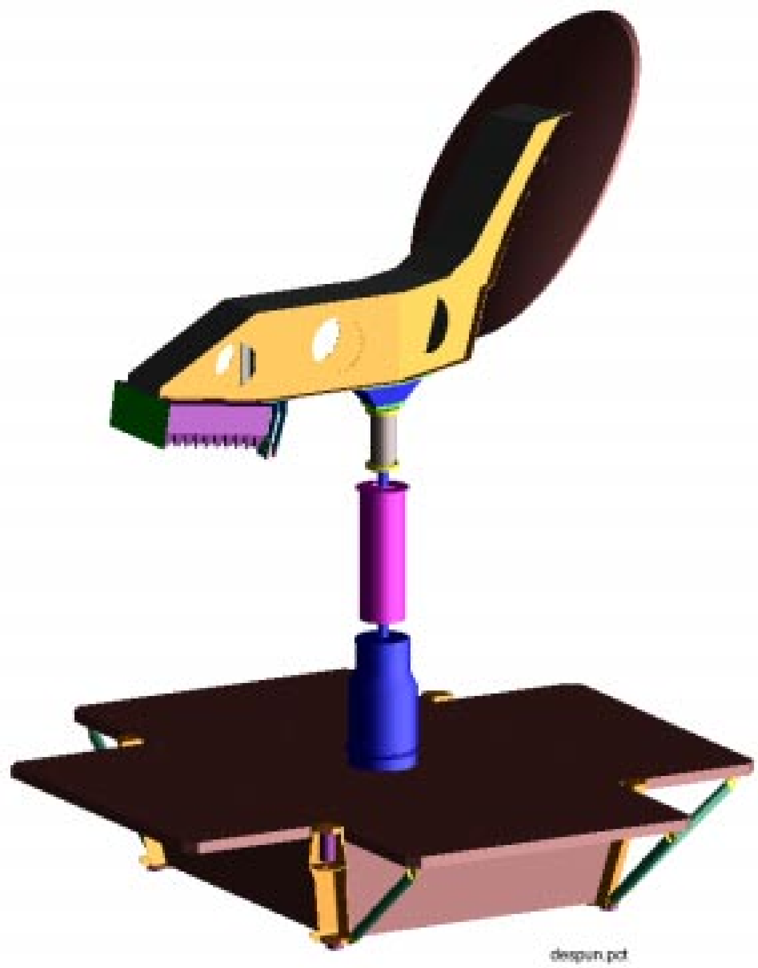
Side Assembly View

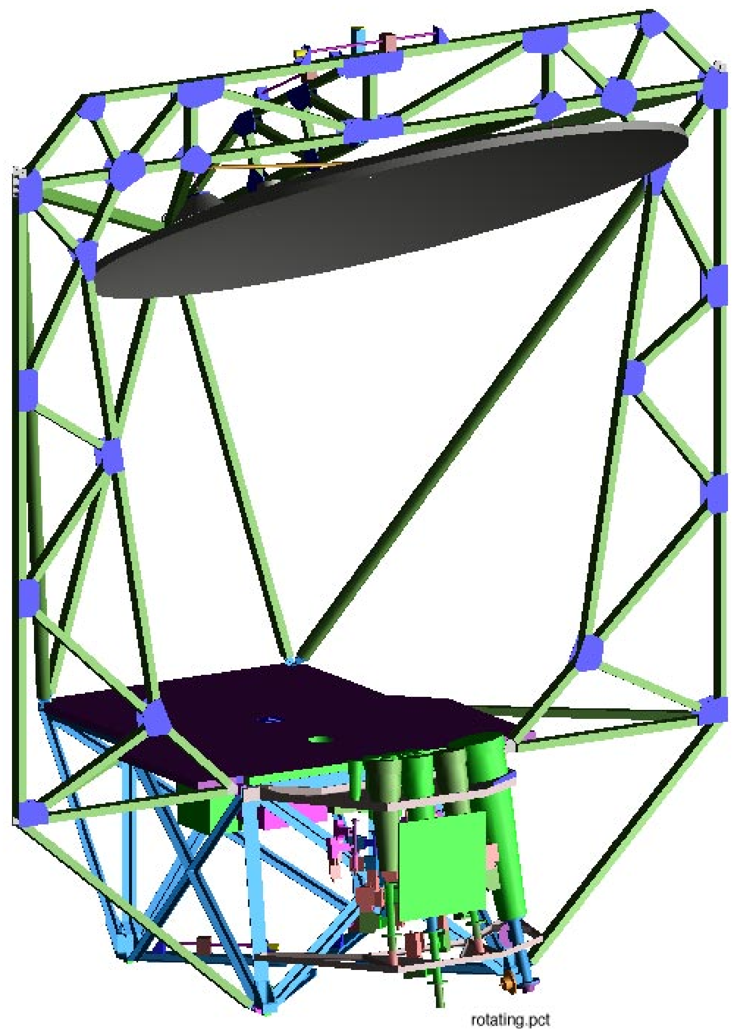


Rear Assembly View



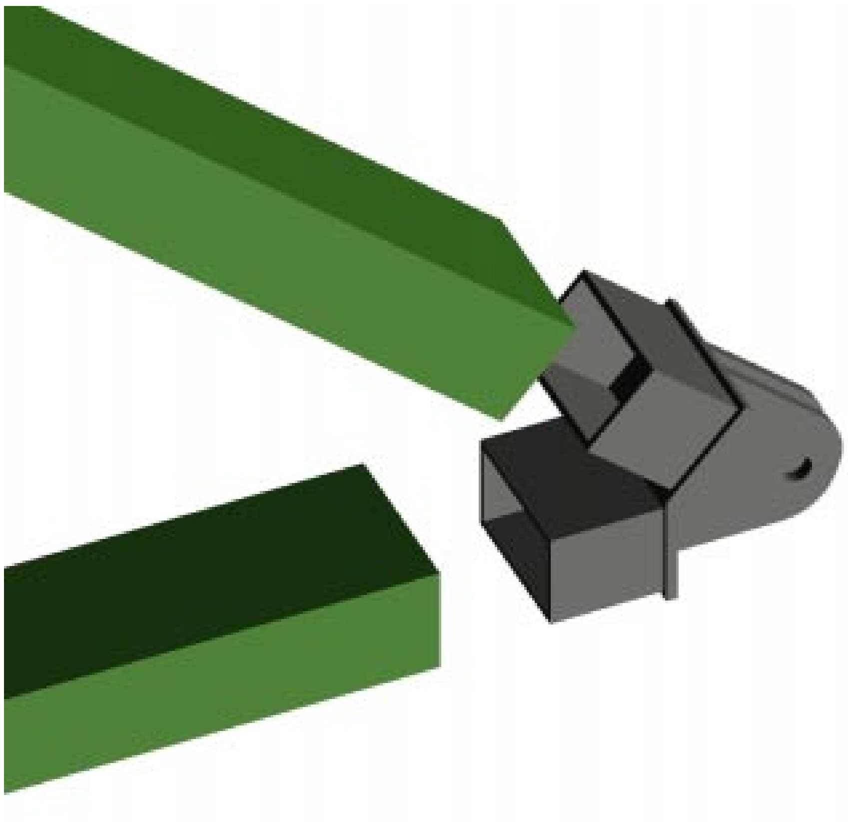
Payload Stationary and Rotating Sections



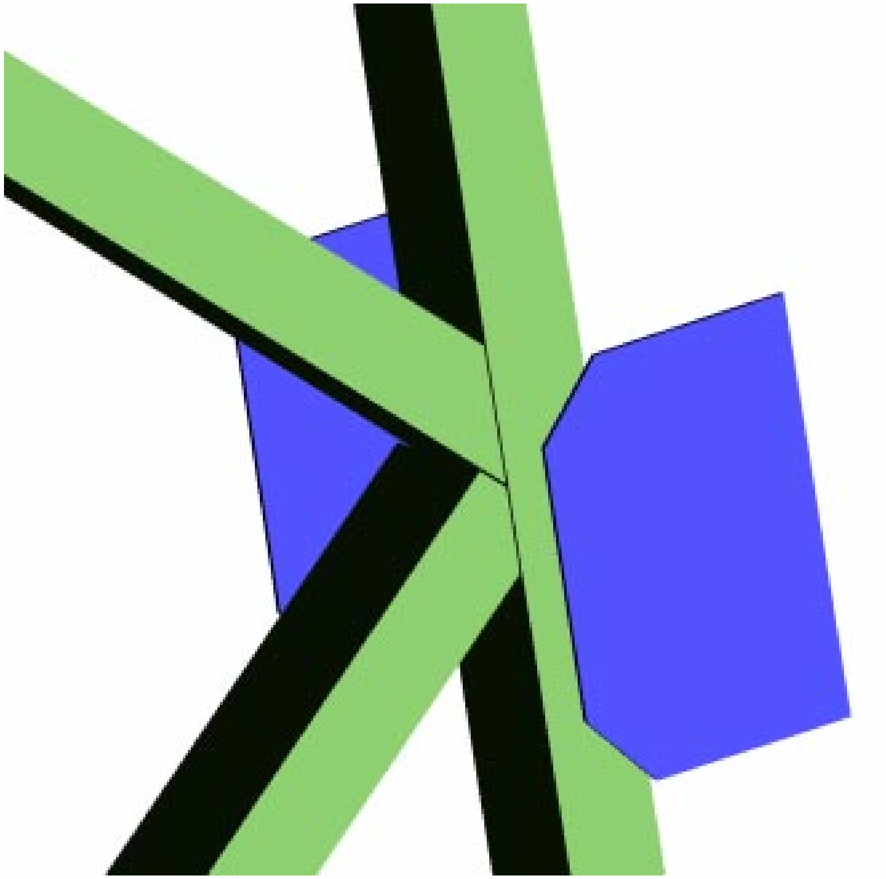


Typical Reflector Support Structure Joints

Tube-Plug Joint



Tube-Gusset Joint

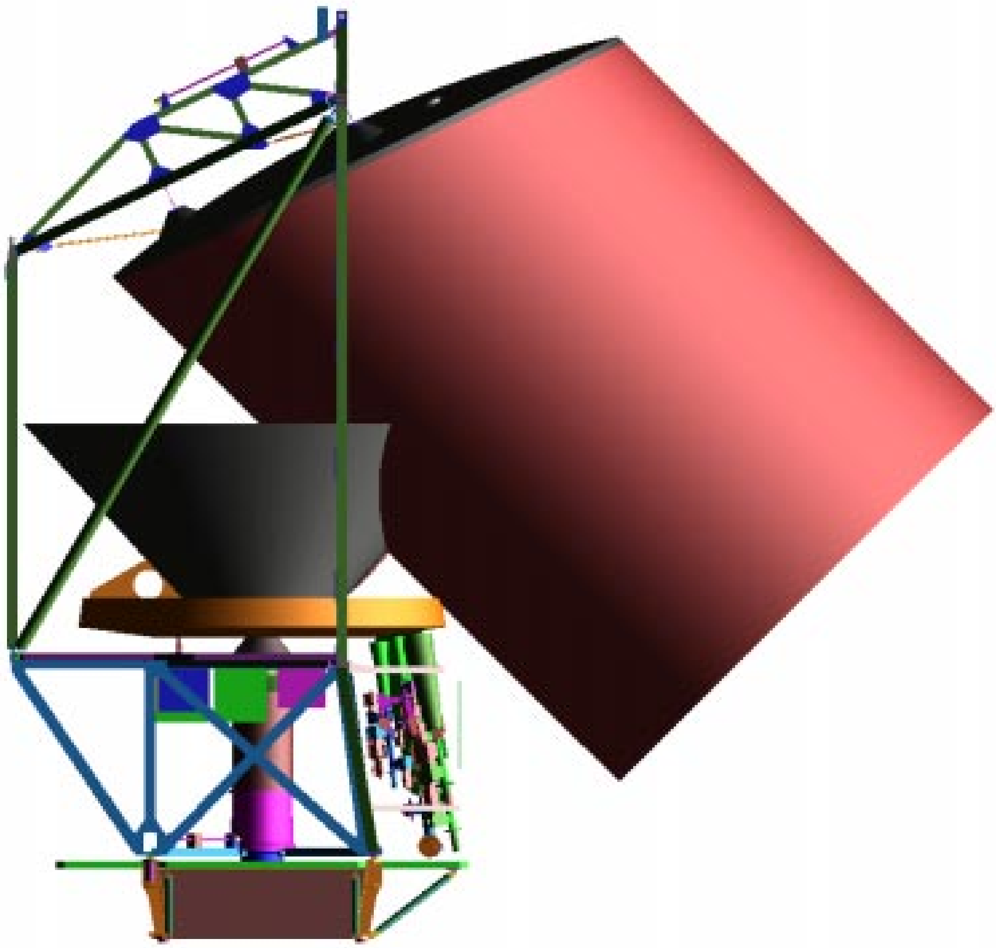


Structure and Component Configuration

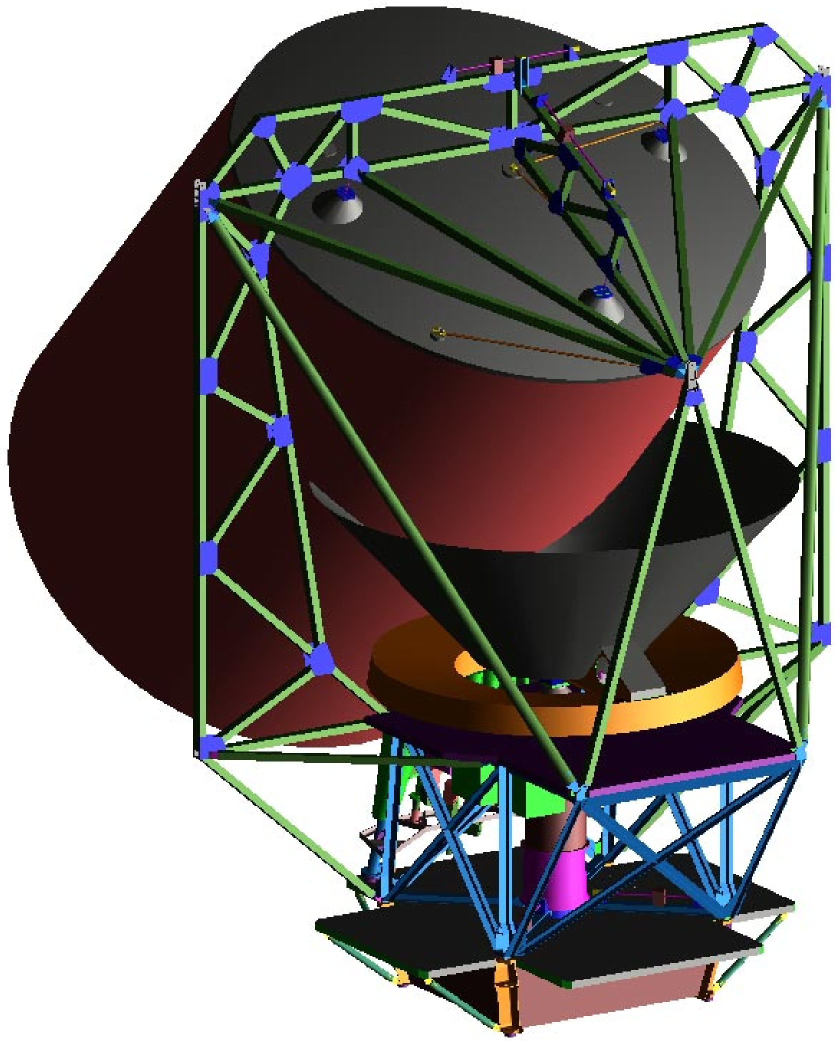
Key Design Parameters:

- Clear Field of View For Reflector Boresight
- Clearance For Cold Sky Reflector and Warm Load Swept Volumes
- Arrange for Dynamic Z Axis Spin Balance
  - Minimize Rotating Section Inertia
- Minimize Cost and Complexity
- Allow Components to Stay Within Their Environmental Parameters
- Enable All Subsystems to Function Properly
- Allow Easy Integration and Access
- Adaptable to ~38” Diameter Spacecraft and Fit In Fairing

Bore Sight Field of View

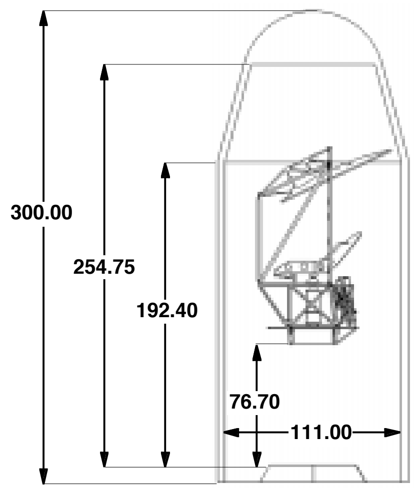


Calibration Source Swept Volumes

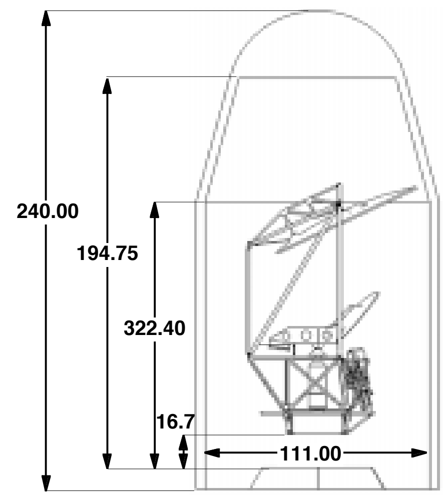


Launch Vehicle Envelopes

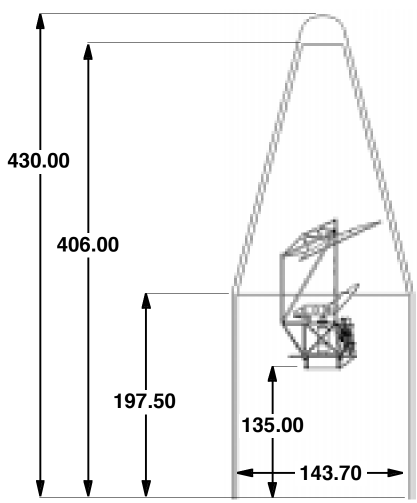
Titan- II 25 Foot Fairing



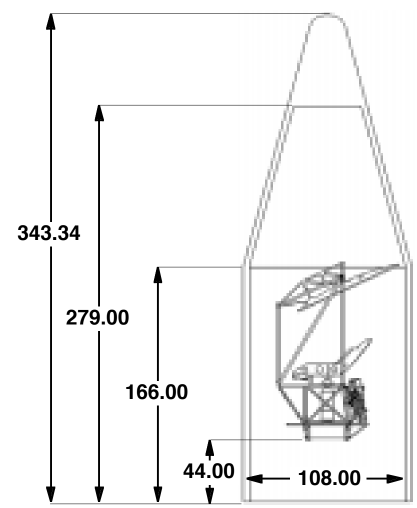
Titan- II 20 Foot Fairing



EELV/MLV



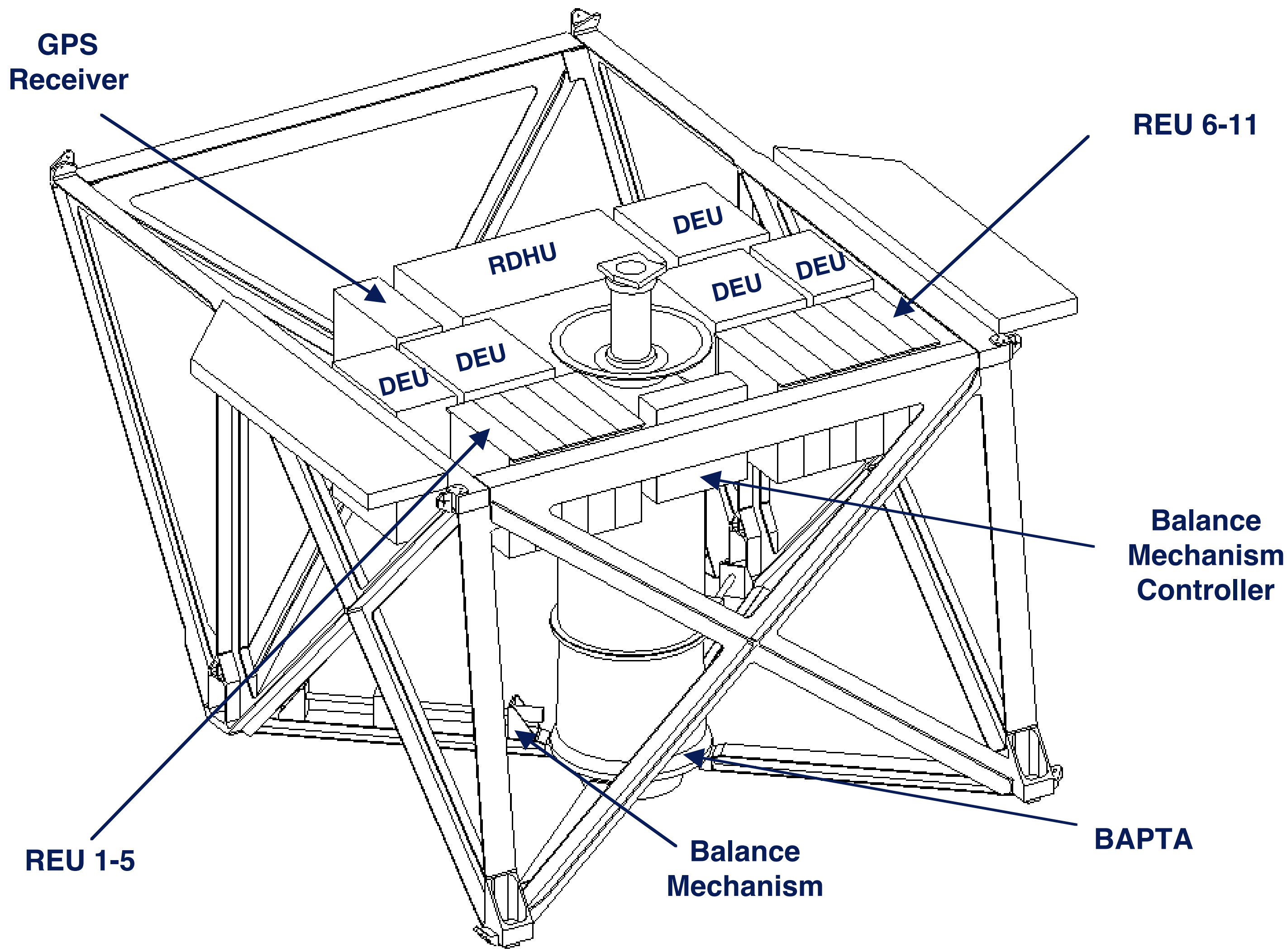
Athena 2



Configuration - Rotating Side

- Top Component Deck With Heat Pipes
- Main Experiment Electrical Components
  - REU's, DEU, RDHU
  - Unique Thermal Stability Requirement
- Arrange for Minimum I_{zz}
  - Inertia Diet
- No Lower Component Deck; X Frame Only
- Components With Less Specific Temperature Requirements Positioned for Static Balance
  - GPS
  - Balance Mechanisms
  - Balance Mechanisms Controller

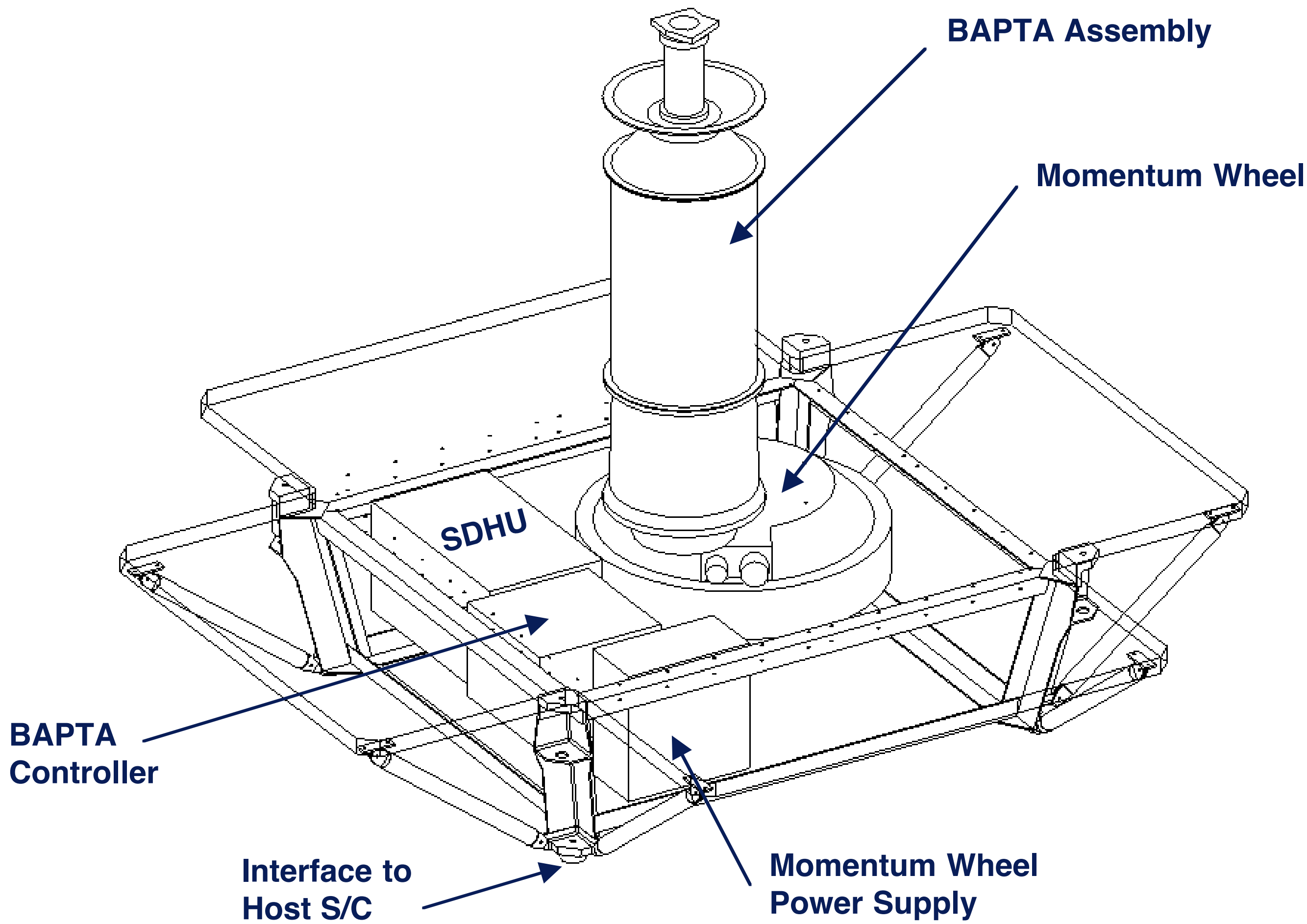
Rotating Side Component Arrangement



Configuration - Stationary Side

- Remain Clear of Rotating Feeds and Canister
- Simple and Adaptable 4 Point Hard Mount To ~38” S/C
- BAPTA and Momentum Wheel Are Mounted To Stationary Deck
  - Components Require Heat Pipes and Designated Radiators
  - SDHU, Moment Wheel Controller, BAPTA Controller
- Some Growth Capability Exists For Future Experiments, Star Trackers, IRU, Etc.

Stationary Side Component Arrangement



Trade Studies (1 of 3)

Canister Construction

- Chose X Frames Over Shear Panels for Lower Cost, Minimum Inertia, and Access
- Optimized Canister and Truss Member Size and Location for Rotating Moment of Inertia, Instrument Stiffness, and Manufacturability

Reflector Support Structure Configuration

(Truss Vs Pylon Vs Street Light)

- Street Light Idea Scrapped Due to Complexity, Weight, Inertia, Balance, Etc.
- Pylon Design Twice As Heavy (With MUCH Larger Inertia), Lower Stiffness
- Chose Truss Configuration to Support Reflector

Reflector Support Structure Joint Configuration

- Bonded Tubes/Gussets Winner Over Machined Fittings and One Piece Picture Frame for Weight, Inertia, and Lower Cost

Trade Studies (2 of 3)

Reflector Support Structure Material

- Aluminum, Titanium, & Composite Considered for Truss and Pylon Reflector Support Structures
- NASTRAN Finite Element Model (FEM) Used for Finding Natural Frequencies, and Determining Pointing Errors at the Feed Bench.
- Conditions Investigated:
  - 1 G in X, Y, and Z Cases
  - Centrifugal Accel at 29.6 Rpm
  - 1 Deg Bulk ΔT
  - 1 Deg Gradient in X, Y, and Z Cases
  - Coefficient of Moisture Expansion (CME)
- Equation Written to Output Relative Displacement of Reflector Focus (Determined As Average of Flexure Mount Displacements) vs. Feed Bench Focus (Average of Feed Bench Mount Displacements)

Trade Studies (3 of 3)

Reflector Support Structure Material (Continued)

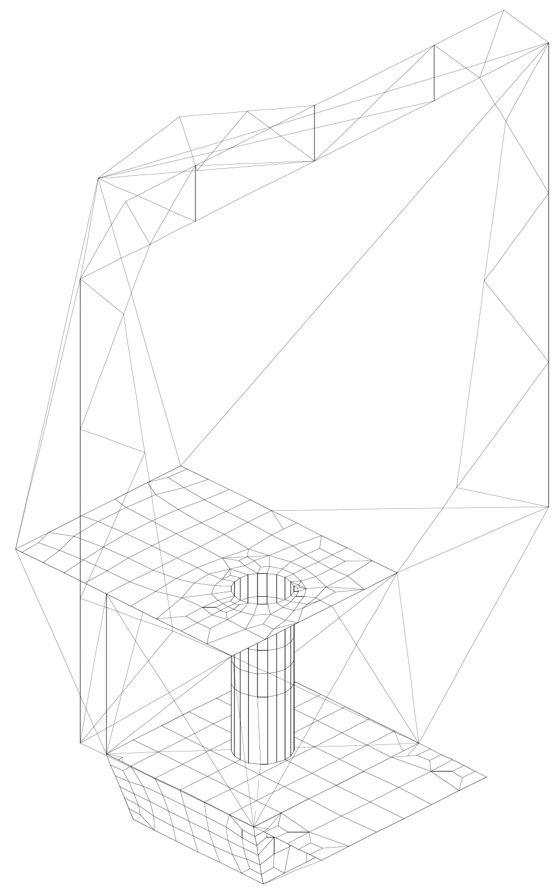
- Not As Sensitive to Temperature As Previously Thought, Requirements Now More Lax
- CME Not Significant (.0016” Defocus vs .070” Allowable)
- PRA Primarily Affected by Motion of the Feed Bench With Respect To BAPTA
- Two Types of Errors
  - Bias Errors: G Release, Bulk ΔT, CME, Centrifugal Accel
  - Transient Errors: Temperature Changes, Jitter
- Titanium Provides Less Performance, Much Higher Spin Inertia at About the Same Cost As Composite
- Composite Clearly Best Performer, but With Added Cost and Risk
  - Composite Chosen Over Aluminum As Most Cost Effective Solution That Still Meets Performance Goals (Spin Inertia Main Driver)

Structural Distortion and Pointing Errors

- Long Term (One Time, Static, or Fixed) Type Errors
  - G Release
  - Centrifugal Acceleration
  - Temperature Change From Ground Alignment to On Orbit Calibration Temperature Distribution
- Short Term (Orbital, or Dynamic) Type Errors
  - Primarily Due to Passing In and Out of Eclipse
  - Temperature “Snapshot” Taken at 22 Points Per Orbit
  - Dynamic Equilibrium
  - Difference Between Maximum Excursions (i.e. Amplitude)
  - Jitter Will Be Evaluated Once Source Information Is Available

Finite Element Model

- **FEM Consists Of:**
  - **~ 4600 DOF**
  - **Plates, Bars, Concentrated Masses, and RBE3 Elements**
- **Used for Natural Frequency, Internal Loads, and Distortion Analysis**
- **Mass Properties Include 20% Contingency**



	Report	FEM
Payload Mass (lb)	644.70	647.39
$Z_{c.g.}$ (in)	35.03	34.95
Rotating I_{zz} (lb-in^2)	215830	214038

Distortion and Pointing Errors

Aluminum Reflector Support Structure Results:

Criteria \ Condition	G Release	Centrifugal Acceleration	Reference Temp. Change	Total Long Term	Total Short Term	Allowable Short Term
Feed Focus DX (EIA, Elev.), in.	-0.00877	-0.00100	-0.01300	-0.02277	0.02360	0.02000
Feed Focus DY (SAA, Azim.), in.	0.02230	0.00003	0.00046	0.02279	0.00066	0.02000
Feed Focus DZ (Defocus), in.	-0.00478	-0.00081	-0.06260	-0.06818	0.08940	0.07000
Feed Bench Rotation (PRA), deg.	TBD	TBD	TBD	TBD	TBD	0.01500

- Composite Chosen For Minimizing Rotating Inertia
- Composite CTE Order of Magnitude Less Than Aluminum
- Specific Stiffness 2.5 Times Higher For Composite

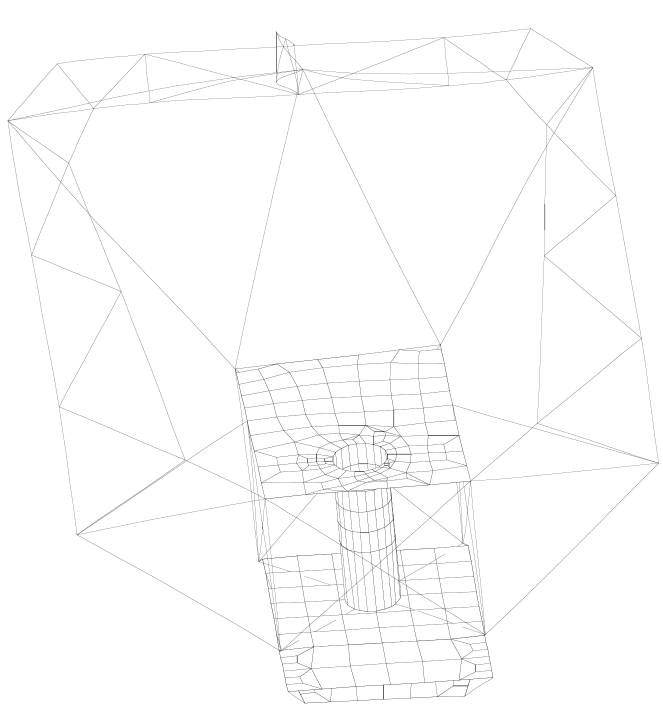
Mass Properties
(Includes 20% Contingency)

Item	Weight (lb)	Izz, c.g. (lb-in^2)	Metric Izz, c.g. (kg-m^2)
ROTATING SIDE			
Feedbench Subsystem Total	95.75	49428.56	14.46
Canister Components Total	192.49	37156.76	10.87
Structure Total	114.75	96410.18	28.21
Balancing Top X Subsystem Total	14.40	17167.61	5.02
Balancing Top Y Subsystem Total	6.60	1540.07	0.45
Balancing Bottom Subsystem Total	19.20	7289.49	2.13
Above Canister Components Total	13.23	6837.42	2.00
ROTATING SIDE TOTAL	**456.42**	**215830.09**	**63.16**
STATIONARY SIDE			
Staionary Deck Components Total	55.62	9461.07	2.77
Calibration Subsystem Total	28.34	5470.41	1.60
Momentum Wheel	73.20	4832.87	1.41
Stationary Deck and Launch Locks	31.12	12066.52	3.53
STATIONARY SIDE TOTAL	**188.28**	32045.47	9.38
PAYLOAD TOTAL	**644.70**		

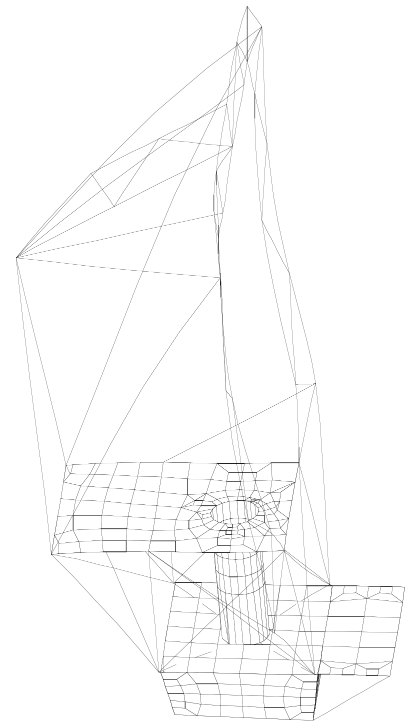
Note: Current Contingency For I_{zz} Is 14% Based on Momentum Wheel Capability
- Work In Progress To Increase I_{zz} Margin

Instrument Natural Frequencies

Note: Displacements Magnified For Clarity

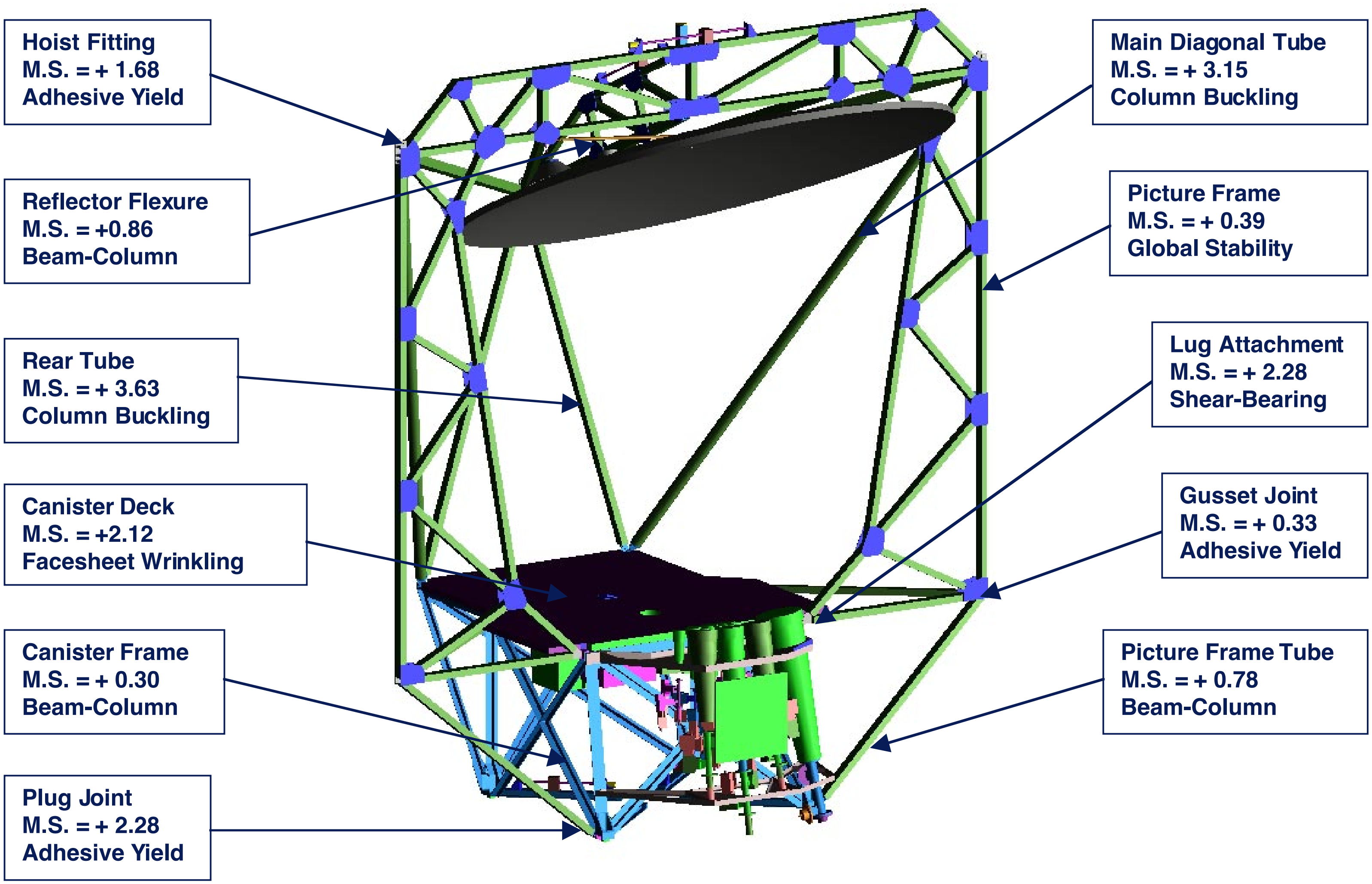


Mode 1: 21.1 Hz
Effective Mass:
X = 0.0 Lb
Y = 262.1 Lb
Z = 0.0 Lb

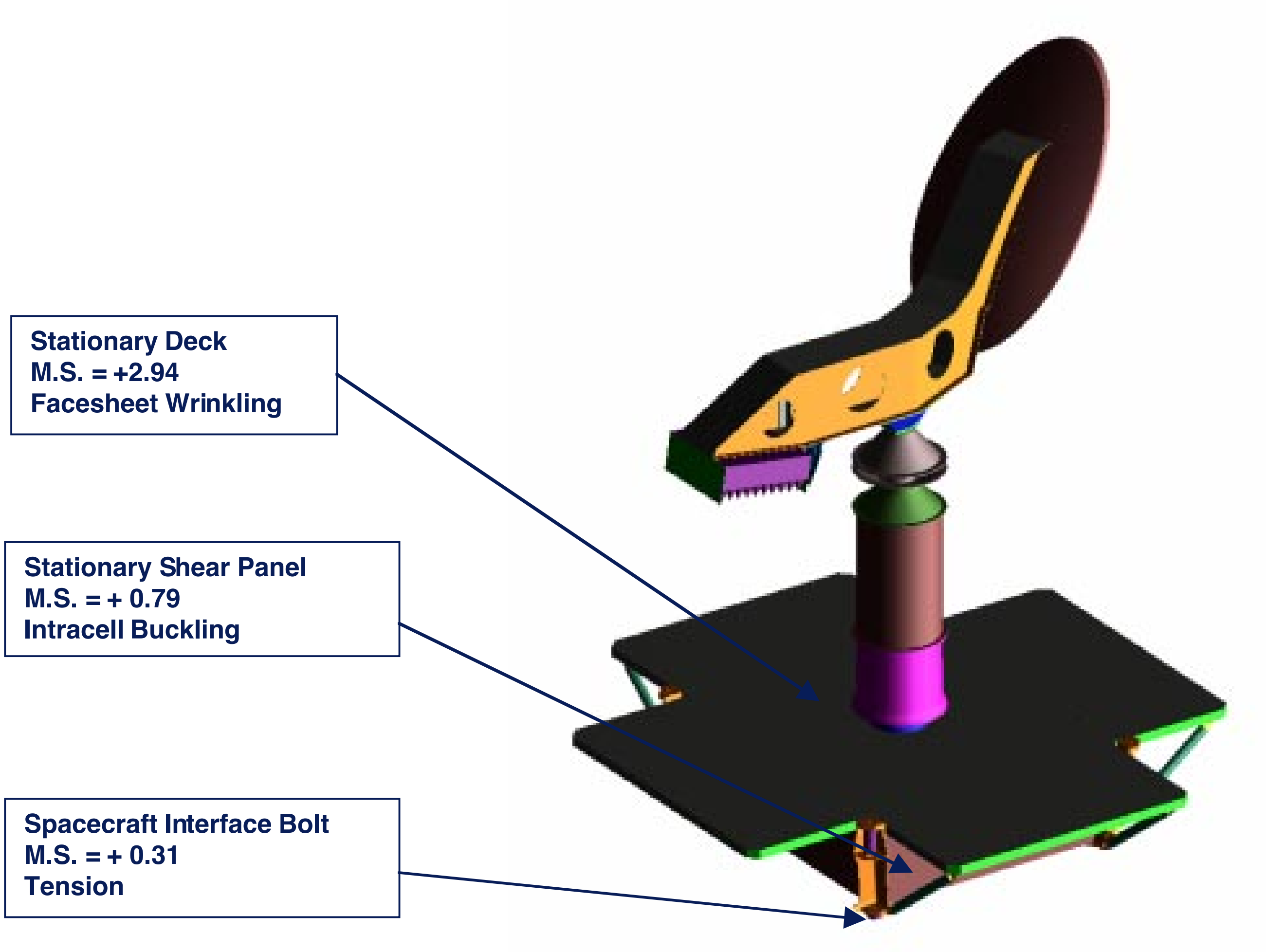


Mode 2: 22.2 Hz
Effective Mass:
X = 269.3 Lb
Y = 0.0 Lb
Z = 1.6 Lb

Preliminary Margins of Safety (1 of 2)



Preliminary Margins of Safety (2 of 2)



Joint Design and Allowables

- Design Criteria Is for Adhesive to Remain Elastic at Test Load

  (1.15 x Limit) and No Failure at 1.50 x Limit Load
- Joint Analysis Will Be Correlated With Test Results. Using Analysis Combined With Heritage for Preliminary Design
- Application of Joint Allowables
  - Evaluate Magnitude of Bond Face Loading for All Joints and Compare with Allowable
  - Use Metallic Plug Fitting for Joints That Do Not Remain Elastic at Test Load
- Ultimate Failure Criteria:
  - 50% of Bond Area Remains Elastic
  - Max Shear Strain < 38 %
  - This Gives The Desirable Result That $P_{fail} \sim 3.75 * P_{yield}$

Joint Development Tests

- Purpose: Risk Reduction / Proof of Concept / Manufacturing Development
- Tests For:
  - Surface Preparation Effectiveness
  - Adhesive Choice
  - Bond Spacing Assessment
  - Analytical Verification of Bond Analysis
- Joint Assembly, Bonding and Testing Will Be Done by NRL and Vendor (If Out-Of-House)
- Test Types to Simulate Critical and Unique Load Paths of the Instrument, Including Lap Shears, Gusset-to-tube, Plug-to-tube, Multi-tube Gusset Joints, and Honeycomb Panel Inserts
- Will Make and Test Flight-like Joints for Design Verification
- Joint Types Tested Will Represent All Joints in Actual Structure

Structure Verification Plan

- **EBB Unit Testing:**

Coupon & Element Tests → Joint Tests → Reflector Support Proof Load → Instrument Modal Survey → Instrument Quasi-Static Loads Test → Instrument Vibro-Acoustic

- **Flight Unit Testing:**

Coupon & Element Tests → Joint Tests → Reflector Support Proof Load → Instrument Vibro-Acoustic

Reliability

- **Reliability**
  - **Bonding and Composite Fabrication Workmanship Specs**
  - **Ultrasound Inspection of All Composite Material in Vicinity of Bonds**
  - **Ultrasound Inspection of All Bonded Joints**
  - **MSFC-SPEC-522B Table 1 Materials**
  - **No Detail Fracture Analysis Is Planned for the WindSat Instrument**

Risk Mitigation

- Bonded Joints:
  - Design Heritage From FUSE, COSTAR, STIS, NICMOS, EOS-AM
  - Joint Testing at NRL
  - Joint Analysis and Correlation With Test Results
  - EBB and Flight Proof Testing at Structure Subsystem Level
- Mass Properties:
  - Detailed Mass Properties Tracking Compared With FEM and Unigraphics Solid Modeling
  - No Weight Reduction of Feed Horns Done Yet
- Unknown Launch Vehicle and Spacecraft:
  - Simple and Adaptable Interface ~38” Diameter
  - Conservative Base Drive Loads Estimate
  - Coupled Loads Analysis When Vehicle and S/C Info Available
- Pointing and Distortion Errors:
  - Composite Materials Virtually Eliminate Structural Distortion and Pointing Errors

Procurement Plan

- Reflector Support Vendor Status
  - Will Buy Composite Tubes and Gussets to Spec
  - Make/Buy Decision for Bonding/Assembly of Truss
  - Will Buy Machined Titanium Plugs and Flexures
- Canister and Stationary Structure Vendor Status
  - Will Buy Honeycomb Decks
  - Will Buy Aluminum Frames and Fittings

Picture Frame Materials Selection Justification (1 of 5)

- Mature Fiber/Resin Systems and Bond Adhesive with Appreciable Flight Heritage
- Proven Laminate Designs: Strut and Gusset Plate
- 7714A Resin:
  - Microcrack Resistance: Rubber-Toughened Epoxy
  - Low Cure Temperature: 260^{o} F
  - Fiber Compatibility: Carbon (Pan and Pitch), Kevlar
  - High Flow
  - Good Tack
  - Processible with Autoclave and Non-autoclave Methods
  - Extensive Fabrication History

Picture Frame Materials Selection Justification (2 of 5)

- 7714A Resin (continued):
  - Low Out Gassing
  - Net Resin Prepreg Capability (5 mil Cured Ply Thickness)
  - Extensively Flight Hardware Heritage
    - Air Force DSCS III: Support Struts and Tank Support Struts
    - Air Force IABS: Tank Support Struts and Solar Array Support Struts
    - LeRC ACTS: Antenna Support Truss
    - GSFC EOS-AM: Primary Truss and Sandwich Panels
    - Commercial Series 7000: Center Cylinder and Struts

Picture Frame Materials Selection Justification (3 of 5)

- M46J Fiber:
  - Good Balance of Strength and Stiffness for Strut Application
  - Moderate Cost
  - Moderate CTE
  - Extensively used in EOS-AM Struts
  - Considerable Mechanical Property Data Base
  - Fiber Sizing Compatible with 7714A Resin
- M55J Fiber:
  - High Stiffness and Strength for Gusset Application
  - Moderate Cost
  - Extensive Industry Use
  - Considerable Mechanical Property Data Base
  - Fiber Sizing Compatible with 7714A Resin

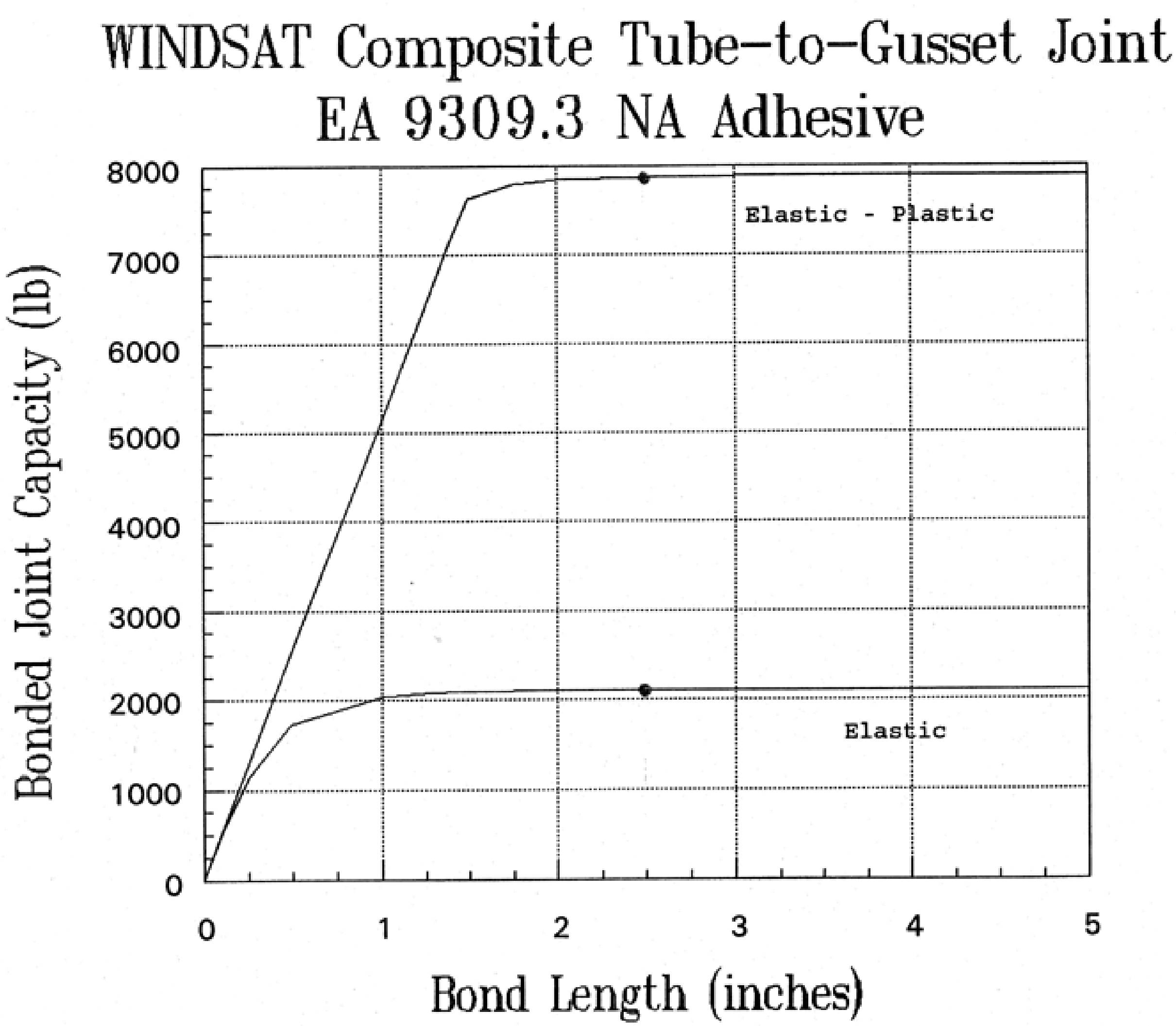
Picture Frame Materials Selection Justification (4 of 5)

- T300 Fiber:
  - High Interlaminar Shear Strength
  - Highly Tolerant of Bond Prep Surface Abrasion
  - Low Cost
  - Extensive Industry Use
  - Considerable Mechanical Property Data Base
  - Fiber Sizing Compatible with 7714A Resin
- Tube Laminate
  - 12 Unidirectional Plies
  - T300/7714A Outer Plies; M46J/7714A Inner Plies
  - $[0_{T300}/0_{2\ M46J}/45_{M46J}/0_{M46J}/-45_{M46J}]_S$
- Gusset Laminate
  - 2 Fabric Plies and 12 Unidirectional Plies
  - T300 (Plain Weave)/7714A Outer Plies; M55J/7714A Inner Plies
  - $[0_{T300PW}/0_{M55J}/30_{M55J}/60_{M55J}/90_{M55J}/120_{M55J}/150_{M55J}]_S$

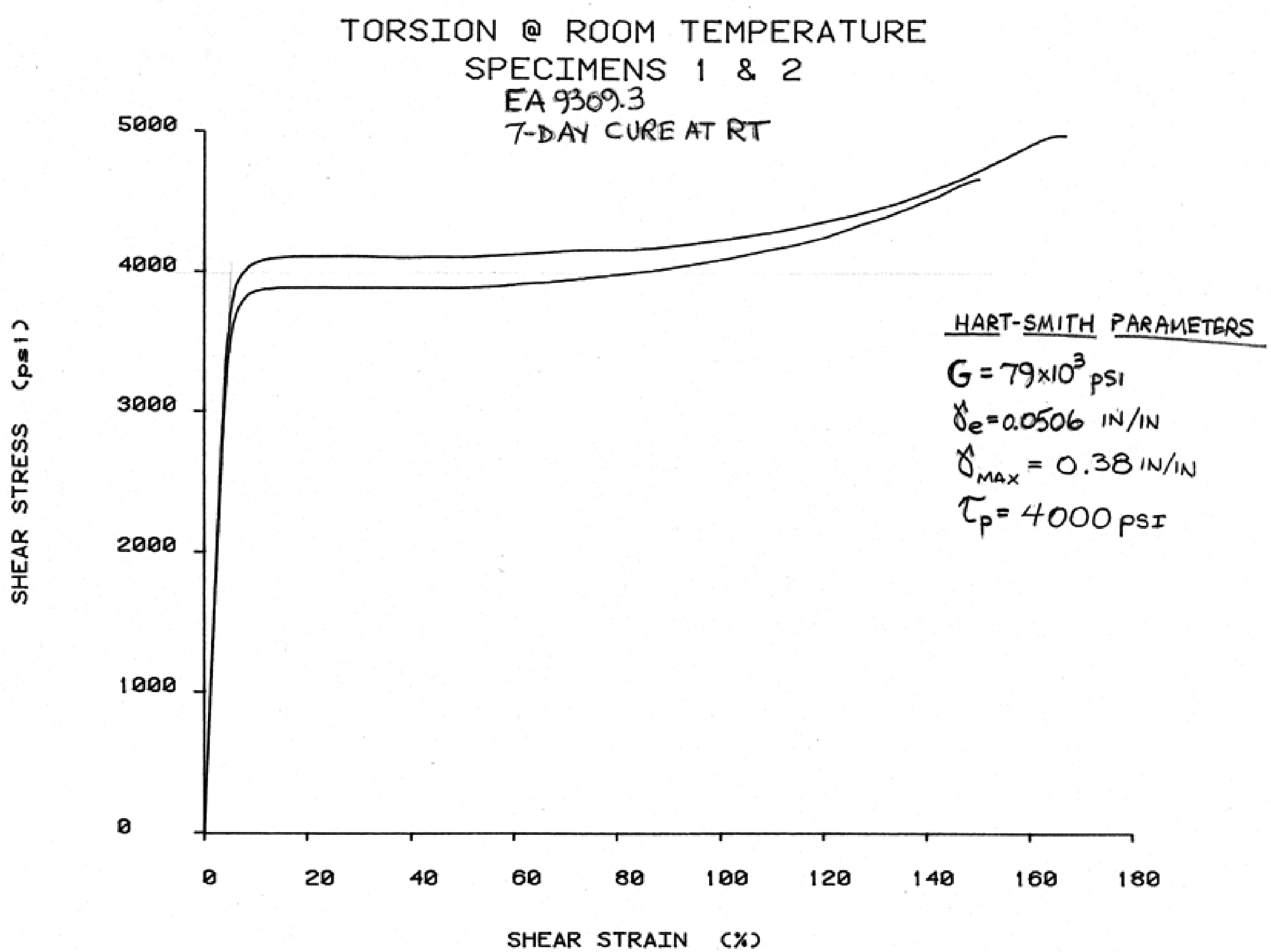
Picture Frame Materials Selection Justification (5 of 5)

- **EA 9309.3 NA Adhesive:**
  - Room Temperature Cure
  - Good Wetting to Titanium and Composites
  - Moderate Viscosity Paste (Thin Bond Lines)
  - High Peel Strength
  - High Shear Strain to Failure
  - Tolerant to Low Temperature Cycling
  - Substantial Flight Heritage:
    - Air Force DSCS III: Support Strut and Tank Support Strut Bonds
    - Air Force IABS: Tank Support Strut and Solar Array Support Strut Bonds
    - Commercial Series 7000: Center Cylinder-to-Ring Joints and Strut Bonds

Bonded Joint Capacity vs Bond Length

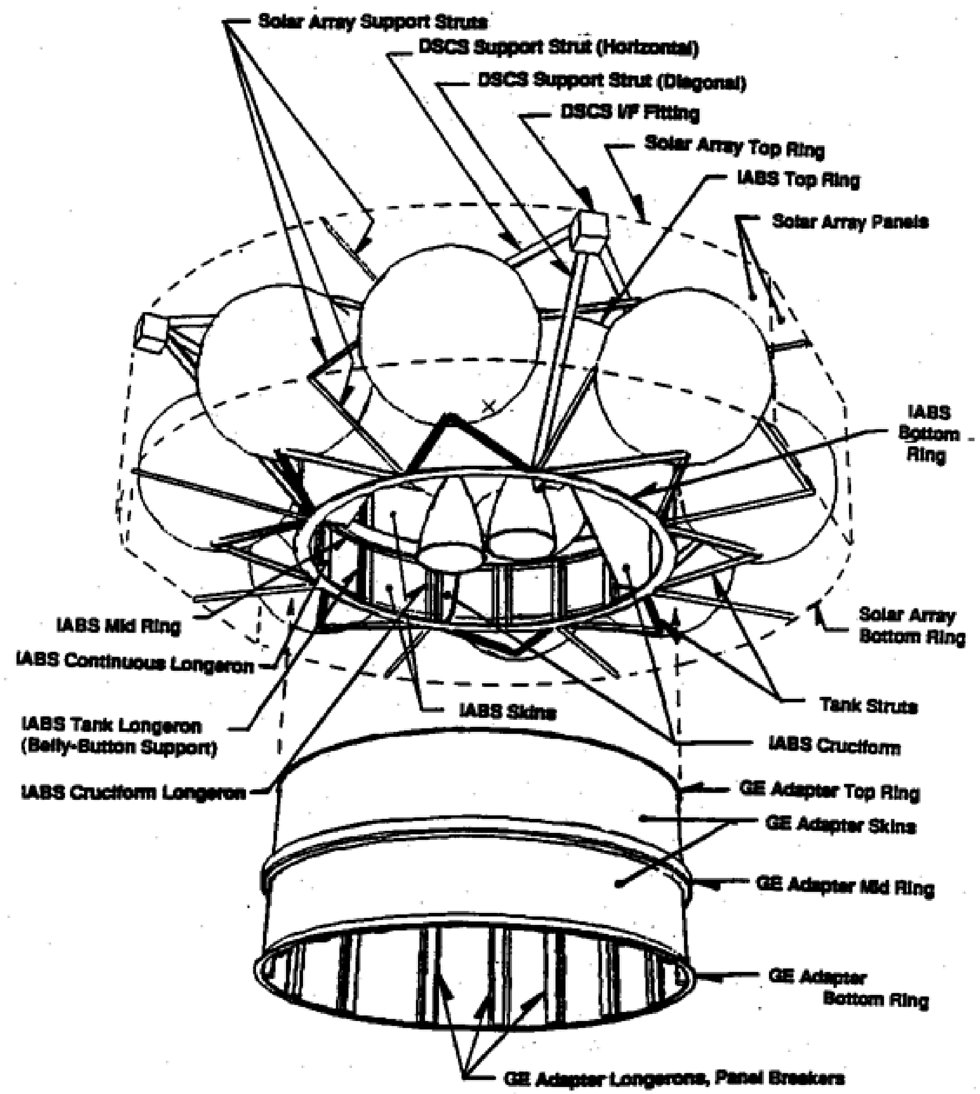


EA 9309.3 NA Stress vs Strain Curve



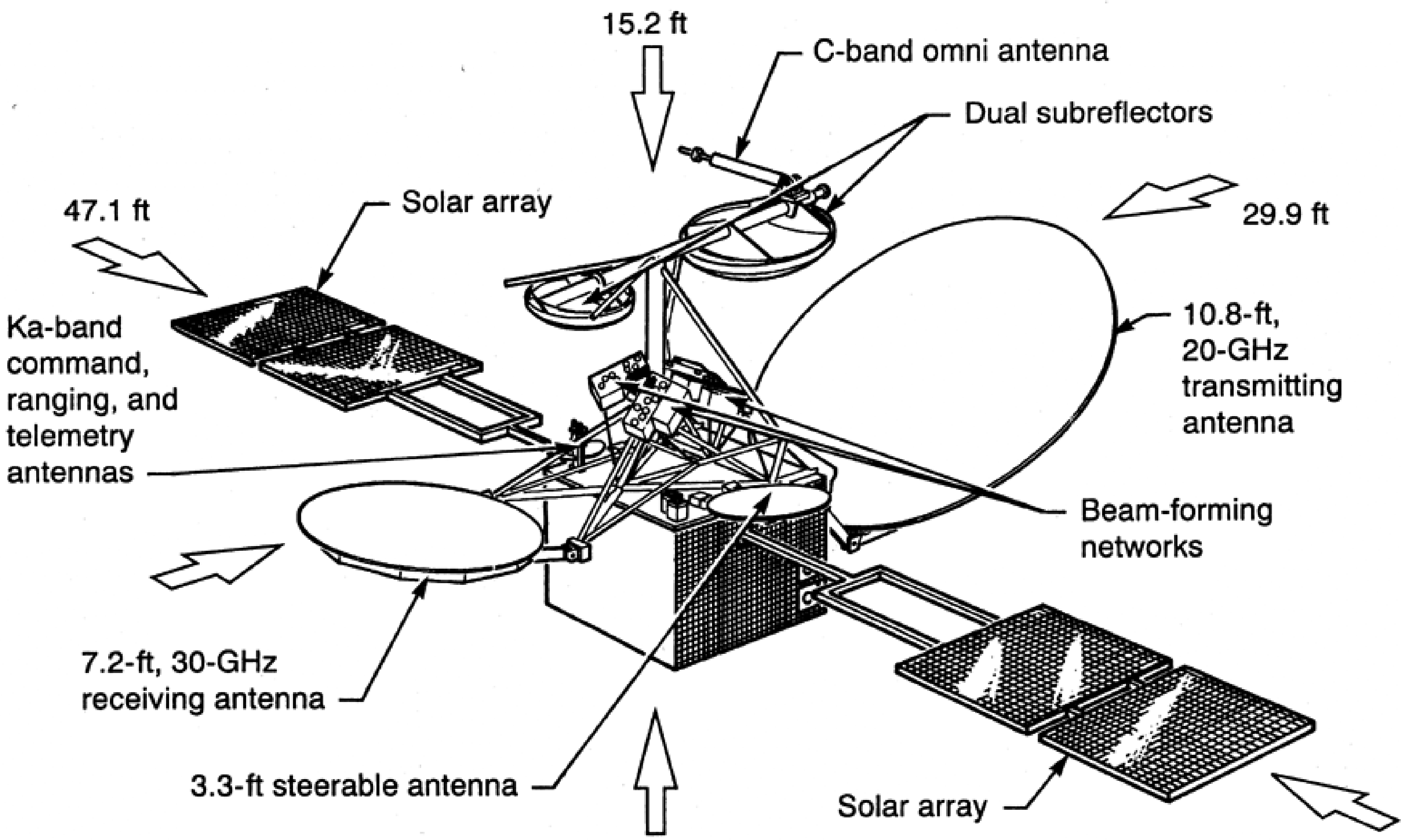
DSCS-3

IABS

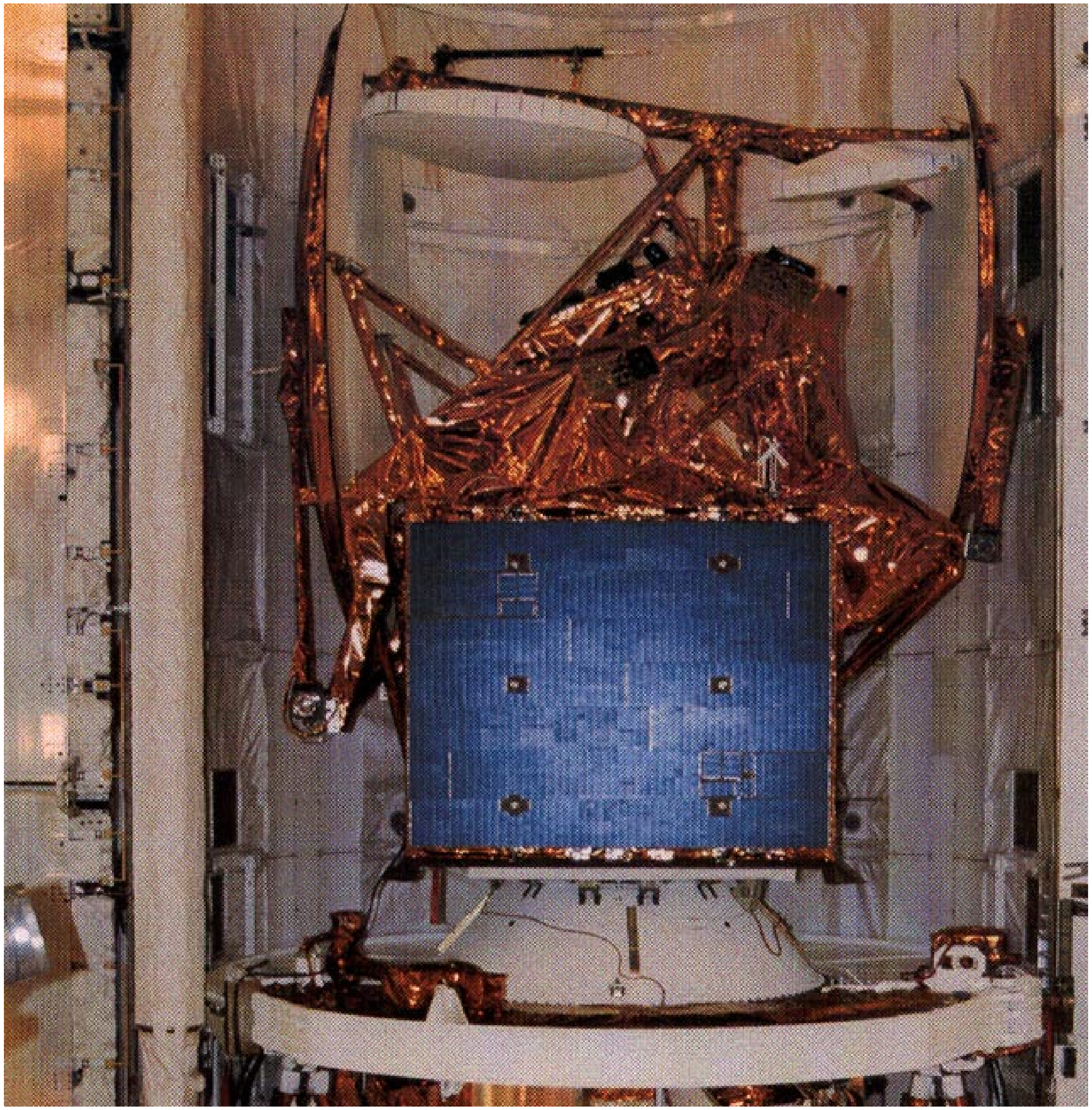


Solar Array Support Struts
DSCS Support Strut (Horizontal)
DSCS Support Strut (Diagonal)
DSCS I/F Fitting
Solar Array Top Ring
IABS Top Ring
Solar Array Panels
IABS Bottom Ring
Solar Array Bottom Ring
Tank Struts
IABS Cruciform
GE Adapter Top Ring
GE Adapter Skins
GE Adapter Mid Ring
GE Adapter Bottom Ring
GE Adapter Longerons, Panel Breakers
IABS Mid Ring
IABS Continuous Longeron
IABS Tank Longeron (Belly-Button Support)
IABS Cruciform Longeron
IABS Skins

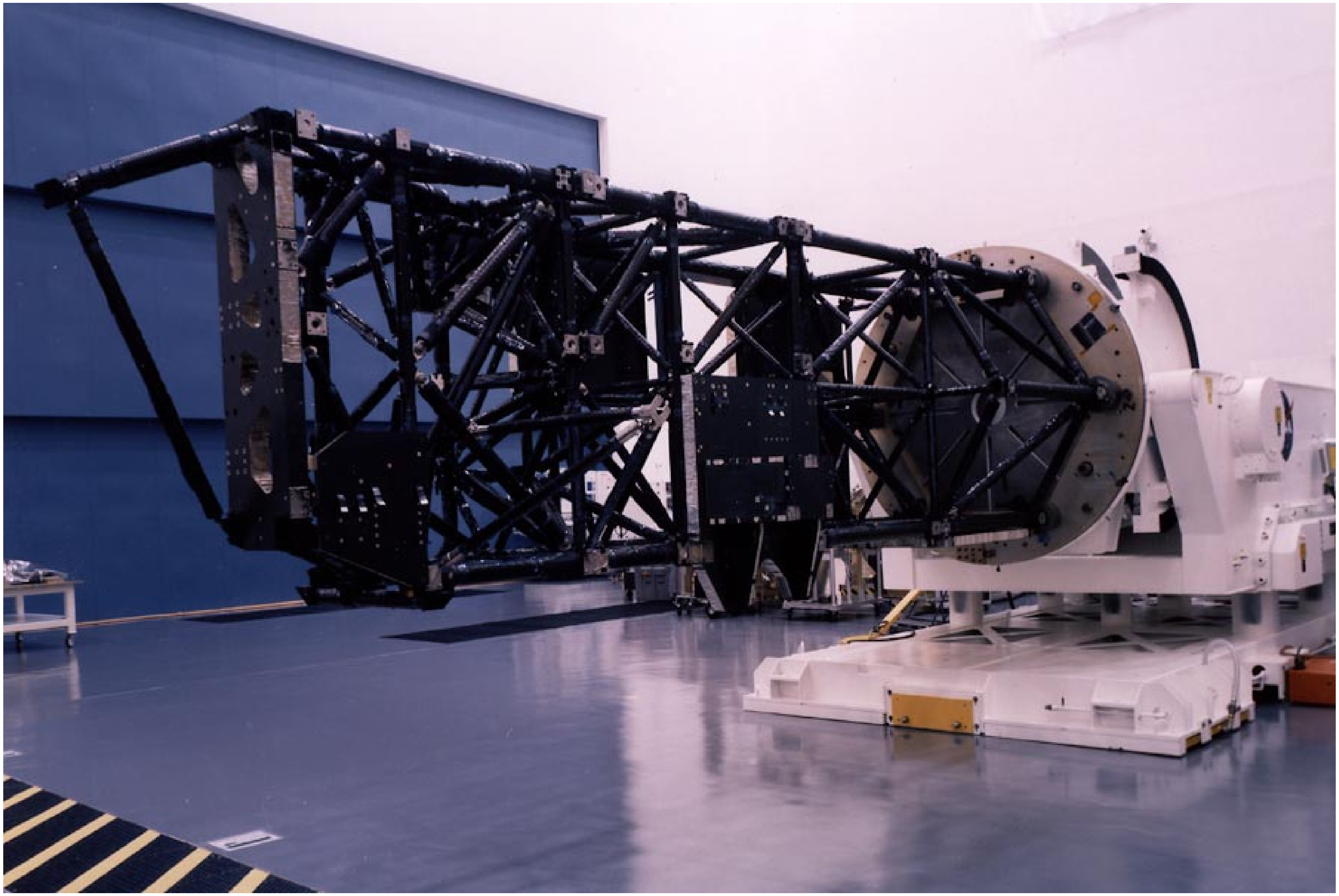
Advanced Communications Technology Satellite (ACTS)



Advanced Communications Technology Satellite (ACTS)



EOS-AM



COMSAT Series 7000 Cylinder

Payload Mechanisms Subsystem

Koss

Mechanisms - Subsystem Component List

- Payload Mechanisms Required
  - Bearing And Power Transfer Assembly (BAPTA)
    - Motor, Encoder, Slip Rings
  - Canister Launch Lock Mechanism
  - Cal Pedestal Bearing & Torsion Launch Support
  - On Orbit Balance Mechanism

Mechanisms - BAPTA / Requirements

Parameter	Requirement
BAPTA Main Bearings Radial Load (Static / Ground Testing)	750 lb
BAPTA Main Bearings Axial Load (Static / Ground Testing)	750 lb
BAPTA Main Bearings Moment (Static / Ground Testing)	5,000 in-lb (Man Hanging On Cannister Edge)
BAPTA Main Bearings Radial Load (Quasistatic Launch)	None (Launch Locked Out)
BAPTA Main Bearings Axial Load (Quasistatic Launch)	None (Launch Locked Out)
BAPTA Main Bearings Moment (Quasistatic Launch)	None (Launch Locked Out)
Payload Rotational Inertia	75 +/- 25% kg m^2
Operational 1st Mode of BAPTA Structure W/Antenna	> 5 Hz (stay away from 0.5 Hz)
Thermal Operating/Non Operational Limits	0C to 40C operating, -20C to 60C Startup, -40C to 60C Survival
Scan Rate	26.6-32.6 rpm (29.6 rpm nominal)
Scan Rate Accuracy	± 0.05%
Operational Life	3 yr operation
Scan Position (eg Encoder) Accuracy	0.0055 deg / 16 bit
Scan Position (eg Encoder) Resolution	512 bits/rev
Pointing Error (Random (eg Runout) / Bias (eg launch shift)	0.006° random and 0.006° bias
Stator Wiring Passthrough	Provide Stationary Wiring Path For 15 TSP / 24 gauge
Rotor	Outer Race (Housing) Rotates
Scan Drive Weight / Drive Elecronics Weight	<32 lb BAPTA / <4 lb BAPTA Elex
Scan Drive Power Consumption / Breakdown	<15W Nominal / < 30W Peak
Mechanical Noise	Cogging Torque <TBD, Torque Ripple <TBD
Electrical Noise	Tailored 461 EMI/EMC

Mechanisms - Cal Pedestal Mount Requirements

Parameter	Requirement	Design
Cold Reflector Position Repeatability XF Axis	+/- 0.050"	+/- 0.002"
Cold Reflector Position Repeatability YF Axis	+/- 0.015"	+/- 0.002"
Cold Reflector Position Repeatability ZF Axis	+/- 0.050"	+/- 0.002"
Cold Reflector Position Repeatability Boresight Elevation (X-Z Plane)	0.5°	<0.05°
Cold Reflector Position Stability Boresight Elevation (X-Z Plane)	0.25°	<0.05°
Cold Reflector Position Repeatability Azimuth (YF/Offset)	.05°	0.01°
Warm Load Position Repeatability XF Axis	+/- 0.100"	+/- 0.002"
Warm Load Position Repeatability YF Axis	+/- 0.100"	+/- 0.002"
Warm Load Position Repeatability ZF Axis	+/- 0.050"	+/- 0.002"
Warm Load Position Repeatability Boresight Elevation (X-Z Plane)	1.0°	<0.05°
Warm Load Position Stability Boresight Elevation (X-Z Plane)	0.25°	<0.05°
Warm Load Position Repeatability Azimuth (YF/Offset)	0.3°	0.01°
Cal Pedestal Bearings Radial Load (Quasistatic Launch)	1100 lb	4000 lb
Cal Pedestal Bearings Axial Load (Quasistatic Launch)	1100 lb	6500 lb
Cal Pedestal Bearings Moment (Quasistatic Launch)	10,000 in-lb	12,000 in-lb

Mechanisms - BAPTA Slip Ring Requirements

Parameter	Requirement
Bus Voltage Min	22 Volts DC
Bus Voltage Max	34 Volts DC
Payload Power	262 Watts Max
Survival Circuit 1 Power	84 Watts @ 22V to 200 Watts @ 34V
Survival Circuit 2 Power	84 Watts @ 22V to 200 Watts @ 34V
Power Ring Max Current	2 Amps DC
Power Ring Margin	1.5 parallel rings per ring
Signal Ring Cross Talk	> -40 dB @ 1MHz
Signal Ring Margin	2 Contacts/Ring & Parallel Rings
Power Ring Current Derating	50%
Stator/Shaft Wiring Passthru	15 TSP's, 24 gauge wire

Mechanisms - BAPTA Slip Ring Requirements

		Slipring List		
Qty	**Type**	**Description**	**Max Resist.**	**Frequency**
9	Power	22-34 VDC Bus Voltage	0.1 ohm	
9	Power	22-34 VDC Bus Return	0.1 ohm	
4	Signal	Differential Payload Serial Control Data (Primary)	10 ohm	1 MHz
4	Signal	Differential Payload Serial Control Data (Secondary)	10 ohm	1 MHz
4	Signal	Differential Payload Serial Status Data (Primary)	10 ohm	1 MHz
4	Signal	Differential Payload Serial Status Data (Secondary)	10 ohm	1 MHz
4	Signal	Differential GPS PPS (Primary)	10 ohm	1 MHz
4	Signal	Differential GPS PPS (Secondary)	10 ohm	1 MHz
2	Signal	Signal Ground Reference	10 ohm	1 MHz
5	Power	Survival Heater Ckt1 Voltage	0.1 ohm	
5	Power	Survival Heater Ckt1 Return	0.1 ohm	
5	Power	Survival Heater Ckt2 Voltage	0.1 ohm	
5	Power	Survival Heater Ckt2 Return	0.1 ohm	
3	Signal	Cannister Temperature	10 ohm	1 Hz
3	Signal	Feedbench Temperature	10 ohm	1 Hz
20	Signal	Spares	10 ohm	1 MHz
10	Power	Spares	0.1 ohm	
100	**Total**			

Mechanisms - BAPTA Changes From SRR

	At SRR	At PDR
• BAPTA Main Bearings Moment	10,000 in-lb.	5,000 in-lb.
• Payload Rotational Inertia	100,000 lb. in ^2 (29 kg m^2)	75 kg m^2
• Rotation Rate Accuracy	0.1%	0.05%
• Encoder Position Accuracy	0.0025°	0.0055°
• Spinning Position Reference Marker	1X/Rev	2X/Rev
• BAPTA Mechanical Pointing Bias & Random Error	0.008°	0.006°
• Life Test Revs	98 Million Revs	49 Million Revs (3 Year Life)
• BAPTA Mass/Volume	30 lb., 1” ID x 6” OD x 16” Long	32 lb BAPTA, 4 lb BAPTA Elex, 0.5” ID x 9” OD x 24” Long

- Added Static Cal Pedestal Requirements, Bearings & Static Cal Pedestal Torsional Launch Lock

Mechanisms - BAPTA Environmental

- Load Requirements From Requirements Table
- Survival Temperature Range BAPTA & BAPTA Electronics: -20C to 60C
- Operational Temperature Range (Full Performance) BAPTA: 0C to 40C
- Operational Temperature Range (Full Performance) BAPTA Electronics: 0C to 40C

Mechanisms - BAPTA Trades
Make vs Buy

BAPTA Make/Buy Trade

	Buy Modified Existing (Hughes, Honeywell, Ball)	Custom In-House Design From Scratch
Lowest Cost	X	
Low Development Risk	X	
Proven Life	X	
Schedule	12 Month EBB, 24 Month Flight	12 Month EBB, 24 Month Flight
Ease of Design Integration	OK	Excellent

Winner: Buy BAPTA

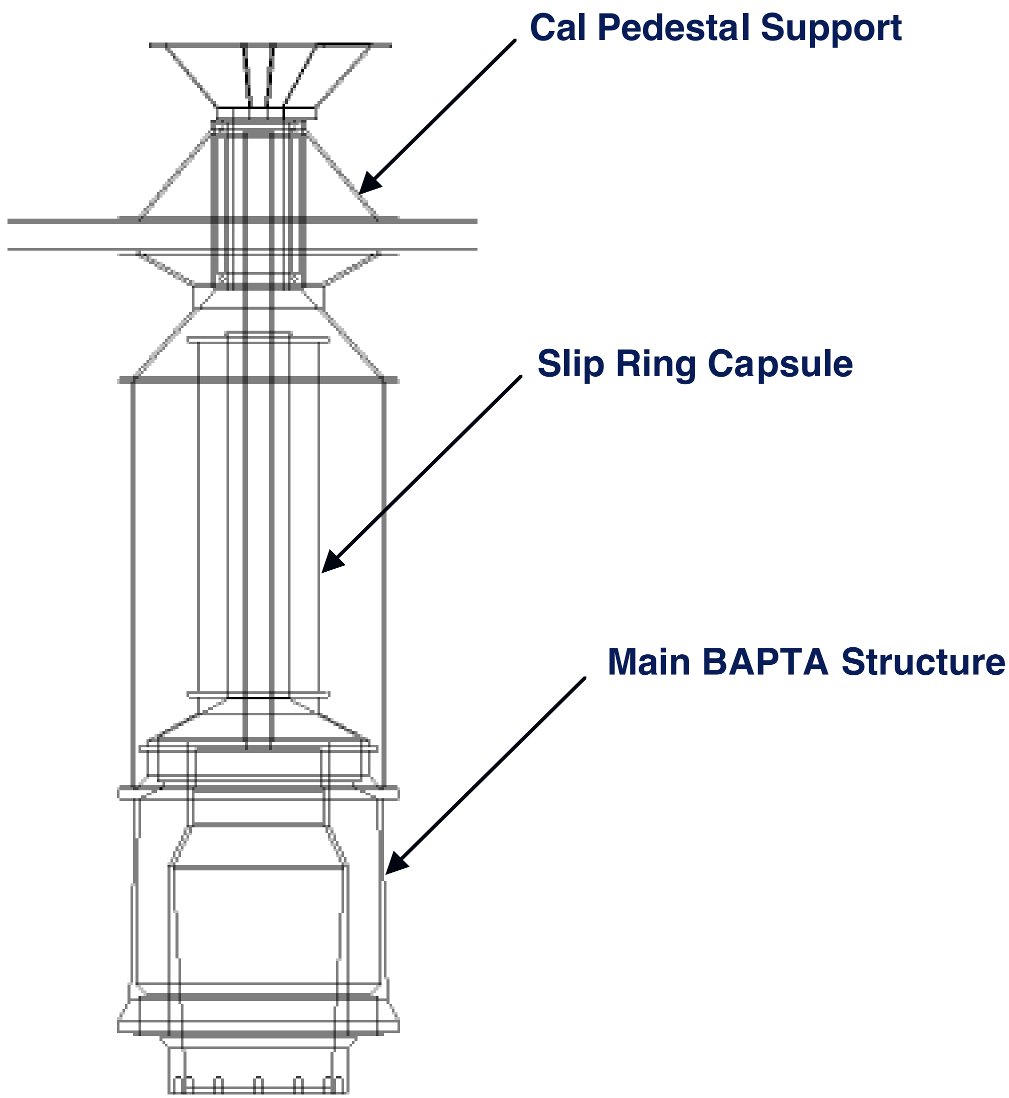
Mechanisms - BAPTA
Design Implementation

- **Proposed Design Is Based On Existing Heritage BAPTA**
  - **Changes Required For WindSat**
    - **Custom Number of Slip Rings For Our Signal / Power Requirements**
    - **DSCS2 Type Slip Ring Design**
      - Selected Based On Trade Study Presented Later
    - **Improved Resolution In Position Feedback Device**
    - **Improved Pointing Accuracy**

Mechanisms - BAPTA
Design Implementation (1 of 2)

- Bearing Design: ABEC 7 / 440C Angular Contact Bearings With Diaphragm Preload & Press Fits
  - Large Margin on Stress Due To Launch Locking Rotating Canister
  - Large Margin on Life Due To Elasto Hydro Dynamic Lubricant Design
- Position Feedback Design: Electrically Redundant Encoder or Resolver
- 2X/Rev Position Integrator Position Device
  - Redundant Photoelectric On Spinning Side
- Motor Design: Brushless DC
- BAPTA Rotor Mounted To Upper Canister Deck and Lower Canister Frame
  - Canister Launch Locks Take Out Load During Launch
- BAPTA Stator Mounted To Stationary Deck and via Bellows To Calibration Load Pedestal

Mechanisms - BAPTA
Design Implementation (2 of 2)

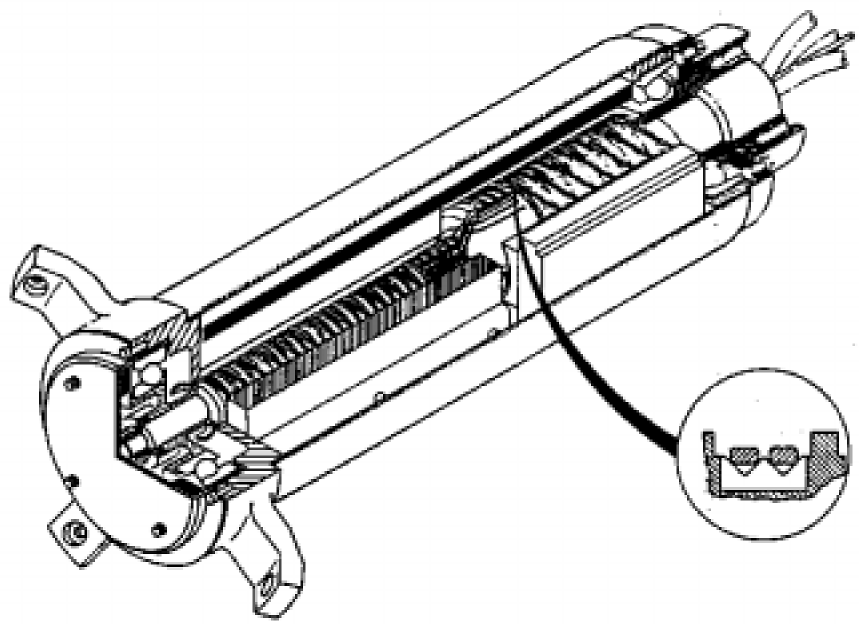


Mechanisms - BAPTA
Slip Ring Trade

	PROVEN		STATE OF THE ART		NEW
	COMPOSITE (SILVER / MOS2)	GOLD MONOFILAMENT & OIL	FIBER BRUSH	ROLL RING	BRUSHLESS BALL BEARING RING & OIL
MANUFACTURER	MANY BUT LITTON & ELECTROTEC MOST SPACE HERITAGE	MANY BUT ELECTROTEC MOST RELEVANT SPACE HERITAGE	LITTON & SCHLIEFRING	HONEYWELL	5TH DIMENSION
PROVEN LIFE	EXCELLENT	VERY GOOD	OK (LIMITED DATA)	OK (LIMITED DATA)	VERY LITTLE DATA
1553 TYPE DATA TRANSFER EVIDENCE	SOME +	SOME	LITTLE	LITTLE	VERY LITTLE DATA
MANUFACTURABILITY	OK	BETTER	BETTER	GOOD	BETTER?
PURGE REQUIRED	YES	NO	NO	NO	NO
ROBUSTNESS	OK	GOOD	BETTER	GOOD+?	GOOD+?
ELECTRICAL NOISE	GOOD	GOOD+	BETTER+	BETTER+	BETTER+?
LIFE TESTABILITY	VERY GOOD	OK	EXCELLENT	EXCELLENT	OK
LIFE TEST UNIT COST	OK	EXCELLENT	OK	OK	EXCELLENT
LIFE TEST UNIT DELIVERY	FAIR	EXCELLENT	OK	OK	GOOD

Winner: Gold Monofilament & Oil

Mechanisms - BAPTA Design Implementation / Slip Rings



- DSCS2 Slip Ring Design
- Up to 20 Years Successful On-Orbit Heritage
- Passed 6 Year Aerospace TVAC Life Test Circa 1970
  - This 30 Yr Old Unit Passed Preliminary Noise Tests At NRL

Mechanisms - BAPTA Design Implementation / Slip Rings

- Slip Ring Design Ball Aerospace DSCS2 Heritage Design
  - All Rings Same As DSCS 2 Power Ring Design
  - Trailing Hairspring Gold Monofilament Wire Riding In Double V-Groove (2 Wires / Ring)
  - Lubrication Selection Based on Life Test Results
    - New BASD 37964 Oil With Improved Properties
    - DSCS2 Heritage Oil BASD 36193
  - 100% Signal Ring Redundancy via Parallel Rings
  - 50% Derated (to 2A/ring) Power Rings, Redundancy 1.5X Required Number of Rings In Parallel
  - 32 Signal Rings + 20 Spare Signal Rings
  - 38 Power Rings + 10 Spare Power Rings
  - Dedicated Shield Rings Between Twisted Shielded Pair Digital Data Rings For Improved Signal to Noise Ratio
  - Self Contained Slip Ring Assembly

Mechanisms - Slip Ring Life Test

Purpose:

- Validate Life & Reduce Risk Associated With 1-6MHz Data Transfer Across Slip Rings
- Demonstrate Successful Performance Using Operational Signal Formats
  - Digital Data Bus Bit Error Performance
  - Power Rings Carrying Expected Current Levels
  - Analog Telemetry Signals
- Detect Deterioration Which Would Eventually Lead to Malfunctions in Operational Signal Formats
  - Open-Circuit or High-Resistance Duration and Frequency-of-Occurrence
  - Contact Resistance

Mechanisms - Slip Ring Life Test

- TVAC Life Test Already Being Conducted At Ball Aerospace
- 26 rpm Unaccelerated Life Test
- Test Start 8/98, Run For At Least 3 Years

Ball Aerospace Life Test

Ball / ElectroTec Baseline

Ball / ElectroTec
Life Test Unit
(New Oil)

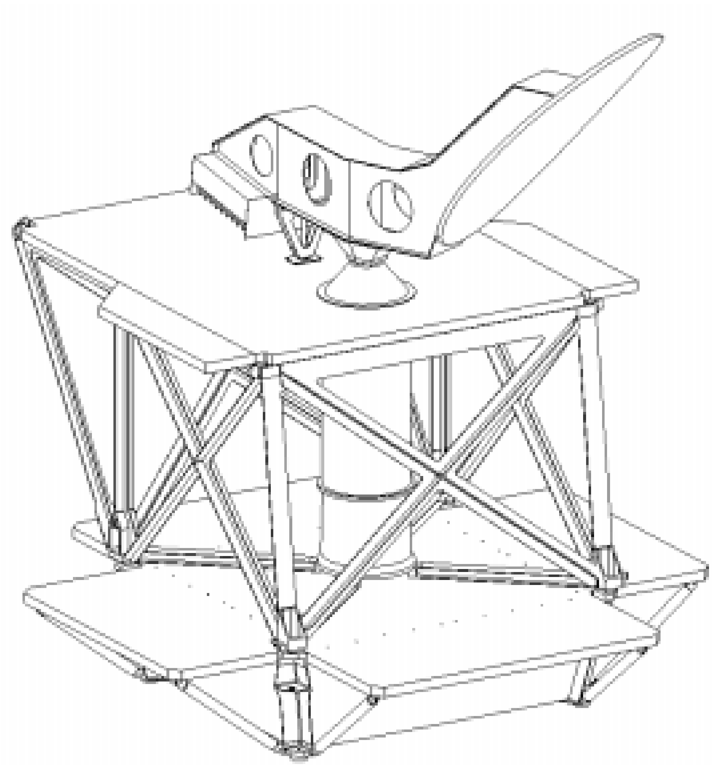
Ball / ElectroTec
Life Test Unit
(Heritage Oil)

Mechanisms - BAPTA Testing

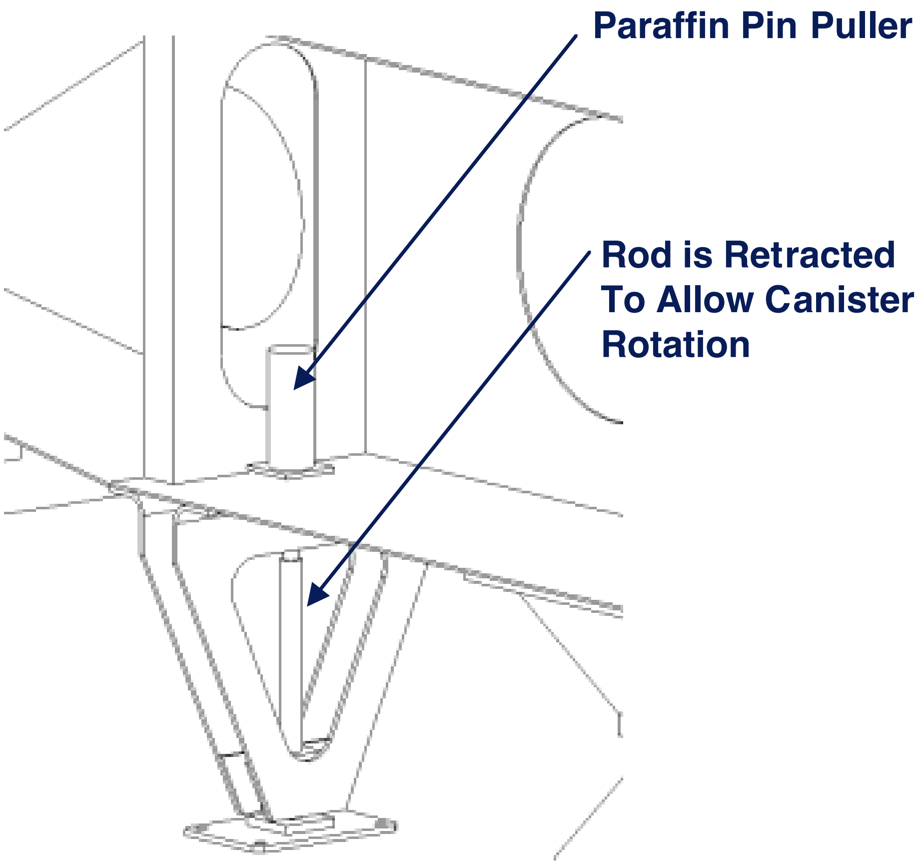
- EBB Unit Tested To Protoflight Levels
- No Dedicated Life Test of BAPTA (Slip Ring Only Life Test)
  - Maximize On-time / Life Cycles of EBB
- Flight Unit Tested To Protoflight Levels

Mechanisms - BAPTA/Static Cal Pedestal Support Design Implementation (1 of 2)

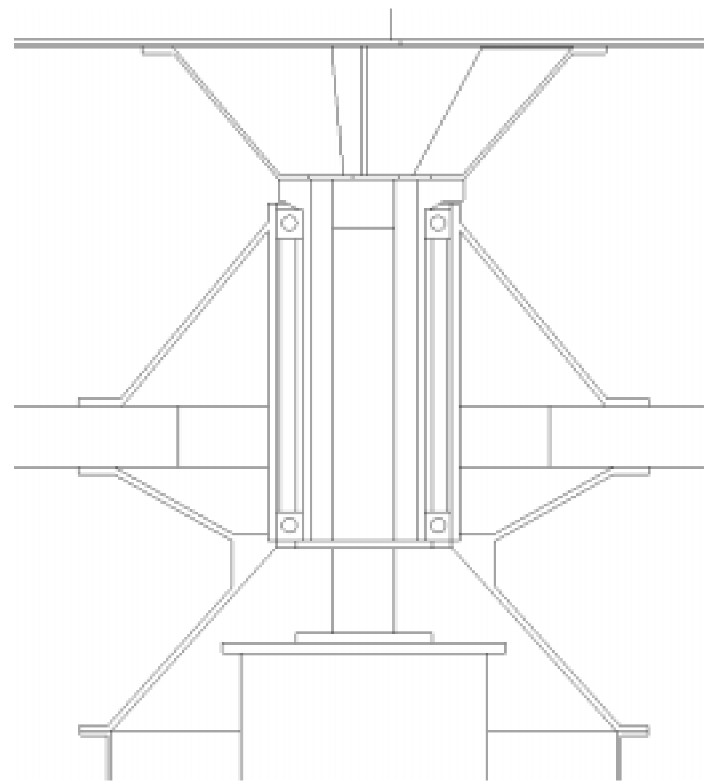
- Cal Pedestal Support Built By NRL
- Stationary Calibration Pedestal Launch Loads Reacted into Canister Top Deck Via Bearing Capsule
- Bearing Capsule Contains 2 Angular Contact Bearings
- Bellows Coupling Torque Tube Interface To Slip Ring Stator of BAPTA
- Pin Released By Paraffin Pin Puller Restrains Torsional Loads During Launch



Mechanisms - BAPTA/Static Cal Pedestal Support Design Implementation (2 of2)



Paraffin Pin Puller Torsion Launch Lock



Cal Pedestal Support Bearings

Mechanisms - Balance Mechanism Requirements

Balance Mechanism

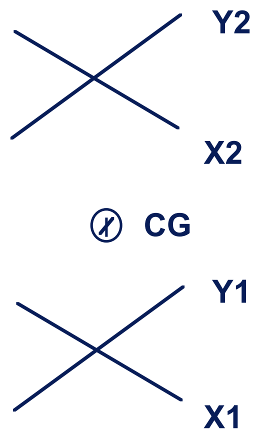
Parameter	Value	Source	Design
Provide Capability For On Orbit Static Balance	Weight and Stroke*	Attitude Control Systems	Weight and Stroke Will be Selected to Meet Requirement With Margin
Provide Capability For On Orbit Dynamic Balance	$<0.1°$ Principle Axes Misalignment	Attitude Control Systems	$<0.01°$ Principle Axes Misalignment
Life (Ground Test + Every 6 Months on Orbit)	25 Cycles Each	Payload Mechanisms	50 Cycles Each

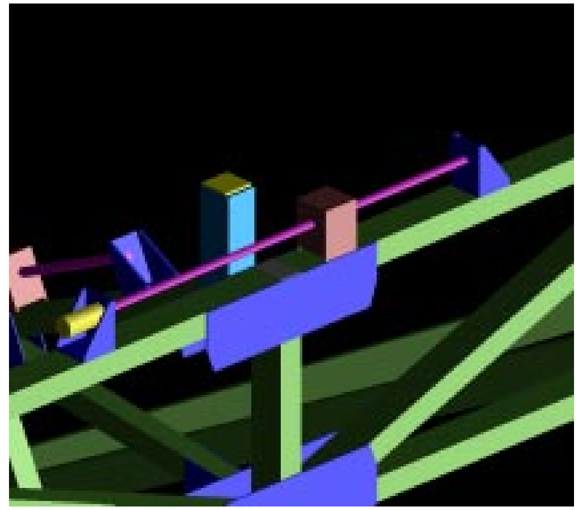
*** Will be Determined Upon Completion of Detail Design by 8/98**

Mechanisms - Balance Mechanism Environmental

- **Withstand Design Loads of MAC Curve**
- **Survival Temperature Range: -80C to +70C**
- **Operational Temperature Range: -60C to +70C**

Mechanisms - Balance Mechanism Implementation





- **4 Trim Balance Mass Leadscrews (X&Y Axes In 2 Planes)**
  - **Trim Balance Mechanism Consists of Balance Mass Whose Position is Adjusted by Motor Driven Leadscrews**
  - **Heritage Mechanism Designs Available**
  - **Command From Ground Based On Determination of On-Orbit Wobble**
  - **Operate Roughly Once Every Six Months**

Mechanisms - Canister Launch Lock Requirements

- Take Canister Axial and Moment Loads During Launch To Provide Canister 1st Mode > 20 Hz
- Allow Free Rotation Of Canister During Ground Testing (1g) and On-Orbit After Launch Lock Release
- Meet Above Requirements Without Degrading Pointing Performance
- Minimize Launch Lock Impact On Spinning Inertia
- Provide Good Load Path From Canister To Spacecraft Structure

Mechanisms - Canister Launch Lock Trades

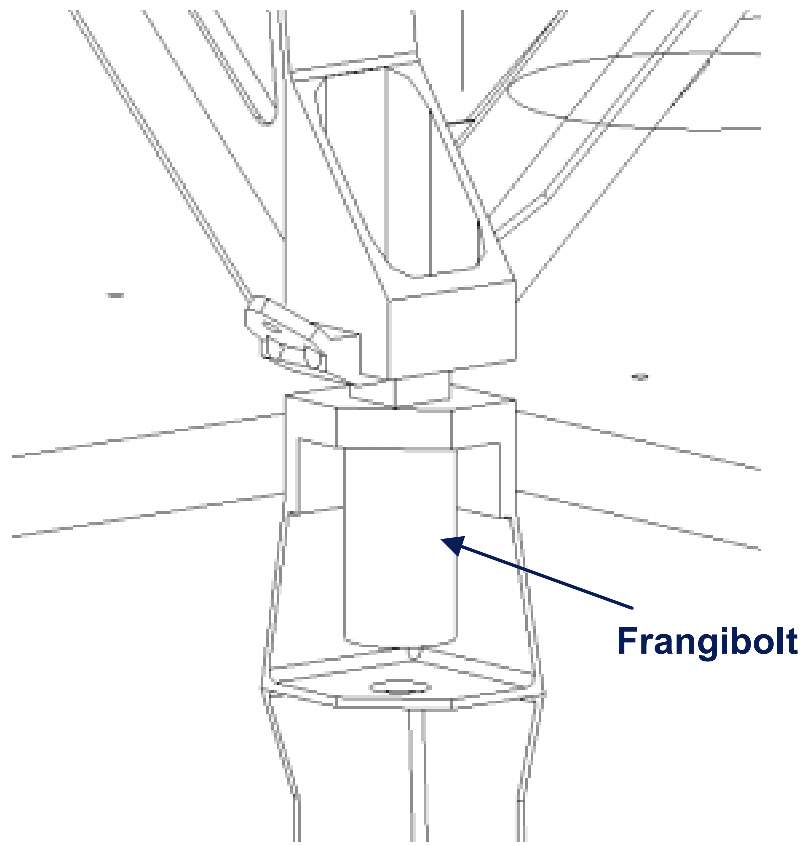
- **No Pyros - Too Costly**

Release Device	Preload	Wt of Device	Wt On Canister	Qual Status / Cost to Qualify	Cost Of Flight Units	Simplicity Of Units	Reliability of Units
TiNi 3/8" Frangibolt	4000 lb	0.25 lb each	0.5 lb total	1/4" qualified qual for 3/8" size cost is low	Low	simplest	very good
Starsys Reverse FASSN	8000 lb	4 lb each	0.75 lb total	will be qualifed by 7/99	High	most complex	very good (new)
Starsys FASSN	7500 lb	4 lb each	6 lb total	qualifed	High	most complex	very good
NEA Cable Release	4000 lb	0.25 lb each	1 lb total	new large cost to qualify	Low	simple	very good (new)

- **Winner TiNi 3/8" Frangibolt**

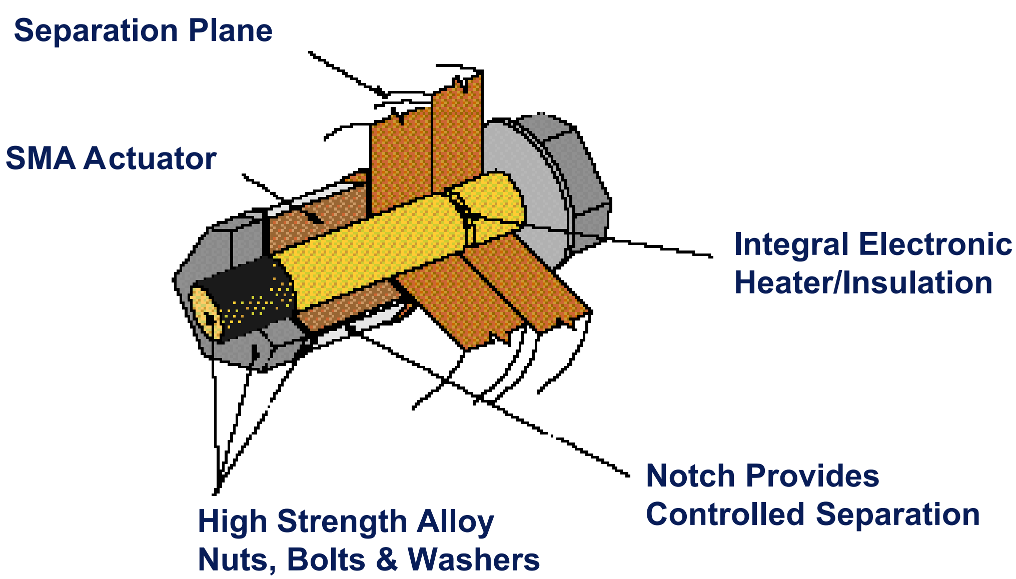
Mechanisms - Canister Launch Lock Implementation

- 4 Pedestals With 3/8” Frangibolts Lock Canister
- Preload 4000 lb (Launch load approx 2500 lb)
- Mounting Plane to Have Adequate Gap Upon Release
- Gap On-Orbit = 2X Gap on Earth Due To Gravity Sag
  - Ground Test: Clearance for 1G Operation
  - On Orbit: Large Gap Margin Against Contact
  - Deflection Provided Via Diaphragm Action of Canister Top and Bottom Decks



Pedestal Joint

Mechanisms - Canister Launch Lock Implementation



Mechanisms - Long Lead Items

- EBB BAPTA - 12 Months
- Flight BAPTA - 24 Months
- Balance Mechanism Motor/Leadscrew - 16 Wk ARO (Flight Build Only)
- Frangibolts - 4 Months To Qual / 5 More Months For Flight Units

Thermal Control Subsystem

Mark Cheung

TCS Requirements

- Nominal Operations
  - Maintain Payload Electronics 0° - 40°C
  - 11°C Prediction Uncertainty
  - All Nominal Sun Angles (Beta Angle)
  - Worst Case Orbital Environments
  - Thermal/Stability ±.010°C/Scan, ±2°C/Orbit

- Non Operational
  - Maintain Payload Electronics -20°C to +60°C
  - 11°C Prediction Uncertainty for Hot Limit
  - 25% Power Margin for Cold Limit
  - All Nominal Sun Angles
  - Worst Case Orbital Environment

TCS Derived Requirements (1 of 2)

- ## Derived Temperature Requirements

PAYLOAD COMPONENTS	SRR REQUIREMENT	PDR REQUIREMENT	
	Operational	Operational	Non-Operational
ROTATING CANISTER			
- RDHU	0 to 40°C	0 to 40°C	-20°C to 60°C
- REU	0 to 40°C $\Delta T/\Delta t = \pm 0.01$ °C/scan	0 to 40°C $\Delta T/\Delta t = \pm 0.01$ °C/scan $\Delta T/\Delta t = \pm 1.0$ °C/orbit (No ellipse) $\Delta T/\Delta t = \pm 2.0$ °C/orbit (With ellipse)	-20°C to 60°C
- BAPTA	0 to 40°C	0 to 40°C	-20°C to 60°C
- Encoder	0 to 40°C	0 to 40°C	-20°C to 60°C
- Balance Drive Unit	TBD	-20°C to 50°C	-20°C to 60°C
- Balance Drive Mechanism	TBD	-60°C to 70°C	-80°C to 70°C
- DEU	0 to 40°C $\Delta T/\Delta t = \pm 0.01$ °C/scan	0 to 40°C $\Delta T/\Delta t = \pm 0.01$ °C/scan $\Delta T/\Delta t = \pm 1.0$ °C/orbit (No ellipse) $\Delta T/\Delta t = \pm 2.0$ °C/orbit (With ellipse)	-20°C to 60°C
- GPS Receiver	TBD	0 to 40°C	-20°C to 60°C
FEEDBENCH			
- LNAs	0 to 40°C $\Delta T/\Delta t = \pm 0.01$ °C/scan	0 to 40°C $\Delta T/\Delta t = \pm 0.01$ °C/scan $\Delta T/\Delta t = \pm 1.0$ °C/orbit (No ellipse) $\Delta T/\Delta t = \pm 2.0$ °C/orbit (With ellipse)	-20°C to 60°C
- Feedhorns	NONE	NONE	NONE
- Isolators	NONE	NONE	NONE
- Attenuators	0 to 40°C	0 to 40°C	-20°C to 60°C
STATIONARY DECK			
- SDHU	0 to 40°C	0 to 40°C	-20°C to 60°C
- Momentum Wheel	0 to 40°C	0 to 40°C	-20°C to 60°C
- Momentum Wheel PS	0 to 40°C	0 to 40°C	-20°C to 60°C
- BAPTA Controller	TBD	0 to 40°C	-20°C to 60°C

TCS Derived Requirements (2 of 2)

- **Passive Element Requirements (Except for the Hot Calibration Source) Derived Through Iteration With Structure Analyst to Obtain Acceptable Temperatures**

PASSIVE ELEMENTS	SRR REQUIREMENT	PDR REQUIREMENT	
		Operational	Non-Operational
Main Reflector:			
- Temperature Range	TBD	-70 to 140°C	-70 to 140°C
- Facesheet ΔT	TBD	< 55°C	NA
- Front to Back Facesheet ΔT	TBD	5.5 °C	NA
Support Structure:			
- Temperature Range	TBD	-50 to 70°C	-50 to 70°C
Hot Calibration Source:			
- Temperature Range	250 to 330 K	250 to 330 K	250 to 330 K
- ΔT Across "Aperture"	< 0.1 °C	< 0.1 °C	NA
- ΔT/Δt	0.05 °C/sec	0.05 °C/sec	NA
Cold Sky Reflector:			
- Temperature Range	TBD	-50 to 120°C	-50 to 120°C
GPS Antenna:			
- Temperature Range	TBD	-85°C to 70°C	-85°C to 70°C

Component Power Dissipation Requirements

PAYLOAD COMPONENTS	POWER DISSIPATION (WITH 40% MARGIN)
ROTATING CANISTER	**218.1 W**
- RDHU	27.7 W
- REU	61.6 W
- DEU	115.1 W
- GPS Receiver	6.7 W
- BAPTA	7.0 W
FEEDBENCH	**44.6 W**
- LNAs	30.8 W
- LNA Regulators	13.2 W
DE-SPUN DECK	**158.4 W**
- SDHU	56.7 W
- Momentum Wheel	70.0 W
- BAPTA Controller	5.6 W
- Momentum Wheel PS	23.3 W
- Encoder	2.8 W

Design Trades (1 of 5)

- Rotating Canister
  - Electronic Box Thermal Management
    - (a) Centralized Deck with CPL/LHP system:
      - Mount All Electronic Boxes on a Separate Deck With Temperature Controlled CPL/LHP System
      - Minimize Survival Heating
      - Minimize Orbital and Seasonal ΔT
      - Increase Design Complexity and Cost
    - (b) Directly Mounted Boxes on Radiator Inboard Surface With Spreader Heat Pipes
      - Simple and Inexpensive
      - Require Higher Survival Heater Power
    - Decision: Heat Pipe System

Design Trades (2 of 5)

- Feedbench
  - LNA to Radiator Heat Transport Device:
    - (a) Heat Straps:
      - Increase Weight and Volume
      - Higher ΔTs Between LNAs and Radiators
    - (b) Copper/Water Micro Heat Pipes:
      - Lighter and Less Volume
      - Smaller ΔTs Between LNAs and Radiators
      - Slightly Higher Cost
      - Need Additional Qualification Tests
    - Decision: Copper/Water Micro Heat Pipes

Design Trades (3 of 5)

- Main Reflector
  - Surface Coating or Bare VDA Surface
    - Coating Surface With Paint Will Reduce Reflector Temperatures
    - Bare Aluminum Surface Can Reach Temperature > 100°C in the Sun
    - Coating Will Adversely Affect RF Performance
    - DECISION: Bare VDA - High Temperatures Acceptable
  - MLI Covering on Reflector Backside or Coating
    - Coating Backside of Reflector Will Reduce Temperature and May Aid in Controlling Lateral ΔT
    - Heat Flow From Front to Back Facesheet May Cause Excessive ΔT Between Front and Back Facesheets - Cause Distortion
    - DECISION: MLI Cover - Predicted Reflector Temperature and Lateral ΔT Are Acceptable

Design Trade (4 of 5)

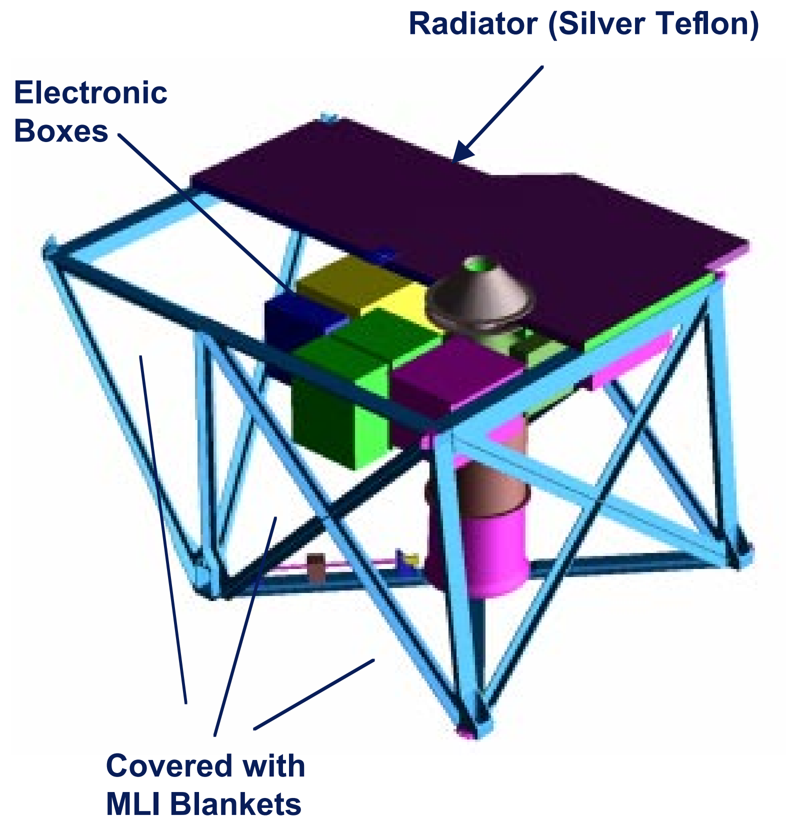
- Main Reflector Support Structure
  - MLI Covering With Temperature Controlled Heaters Will Provide Accurate Temperature and ΔT Control Between Structure Members: Rejected for High Power
  - MLI Covering Without Heaters May Cause Greater Member-to-member ΔT Due to Variations in MLI Effective Emittances: Rejected for High ΔT
  - MLI Covering (Aluminized Kapton) Could Increase RF Scattering Into Reflector: Rejected for RF
  - White Paint (Low α / High ε) Coating Will Cause Some Structure Members to Experience Extremely Low Temperatures (<-60^{o}C) - Large Temperature Difference Between Ground Calibration and On-Orbit Operation: Rejected Structural Impact

Design Trades (5 of 5)

- **Main Reflector Support Structure (Cont.)**
  - **Black Paint (High α / High ε, $\alpha/\varepsilon \sim 1$) Will Maintain Temperatures**
  - **Optically Treated Tape Can Provide Low α / Low ε, $\alpha/\varepsilon \sim 1$ So That Temperatures Can Be Maintained at Relatively High Temperatures While Also Dampening Rate of Temperature Change (Due to Low ε)**

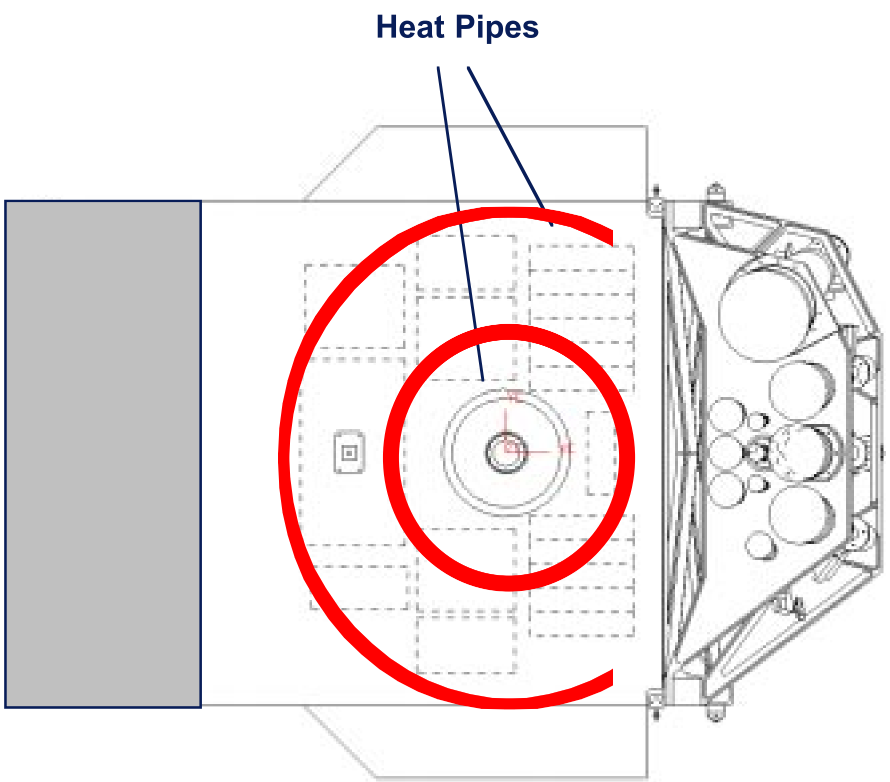
DECISION: Tape With $\alpha = 0.15$, $\varepsilon = 0.15$

Thermal Design Summary (1 of 8)



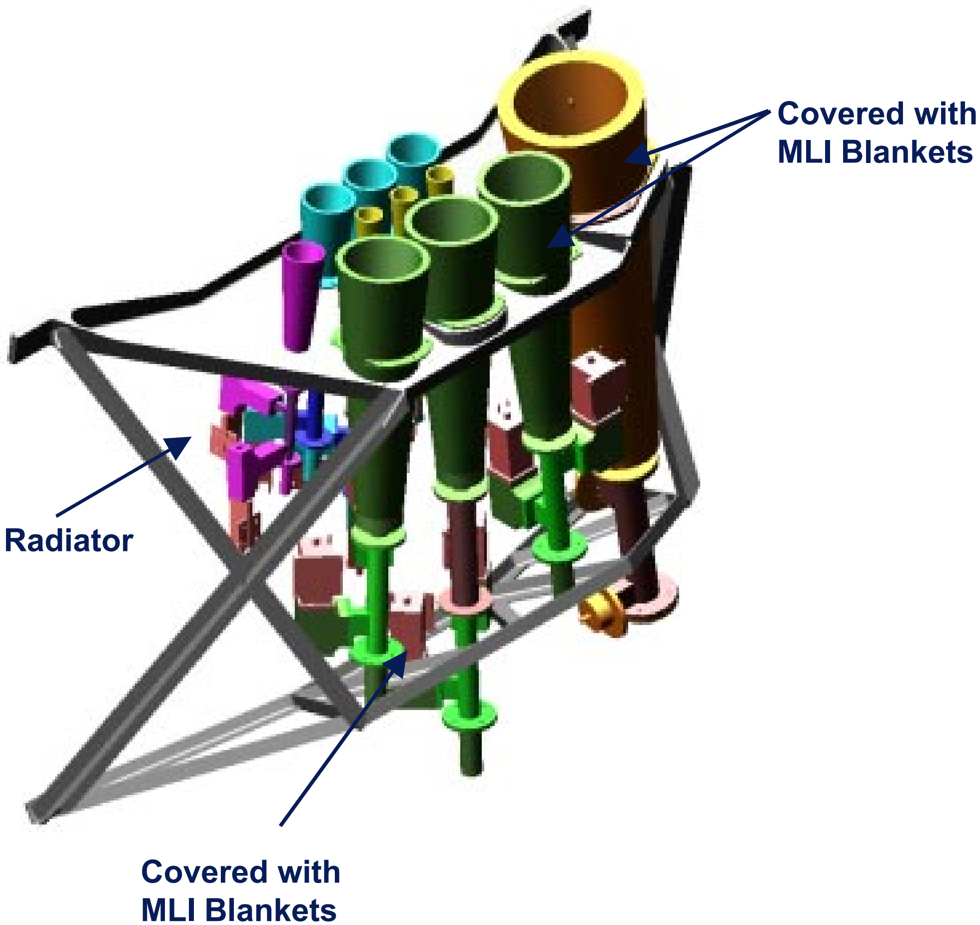
- Rotating Canister
  - 10 Layer MLI Blankets Cover Sides and Bottom of Canister
    - Minimize Heat Exchange From Canister to Space
    - Minimize Canister Structure ΔT
  - Top Canister Panel Designated As Radiator and Mounting Panel for Electronic Boxes
  - Electronic Boxes Mounted on Inboard Radiator Surface
  - 10 Mil Silver Teflon Coating on Radiator Outboard Surface

Thermal Design Summary (2 of 8)



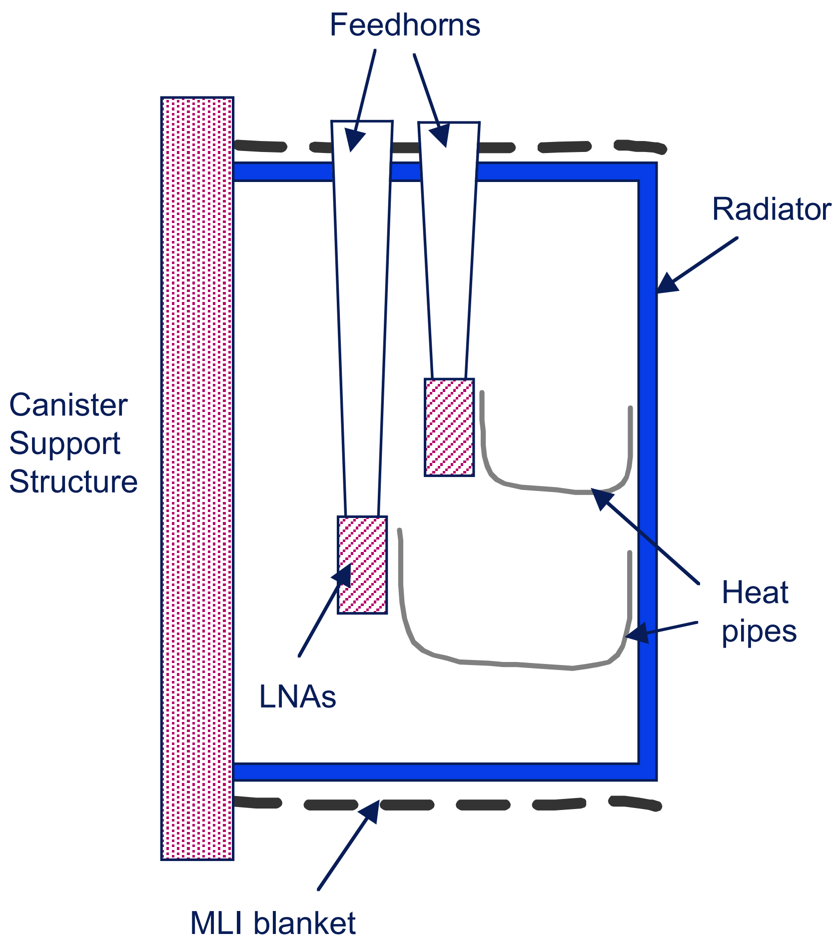
- Rotating Canister (Cont.)
  - Two (2) Aluminum/ammonia Heat Pipes on Outboard Radiator Surface to Minimize Lateral ΔT
    - 5/8” OD
    - Transport Limit: 10,000 W-in
    - Bent Along the Spin Radius to Compensate Rotational Acceleration
  - Employ System Thermal Mass to Maintain $\Delta T/\Delta time$ Requirement
  - Thermostatically Controlled Survival Heaters (~130W Total) Attached to Individual Boxes to Keep Above -20 °C

Thermal Design Summary (3 of 8)



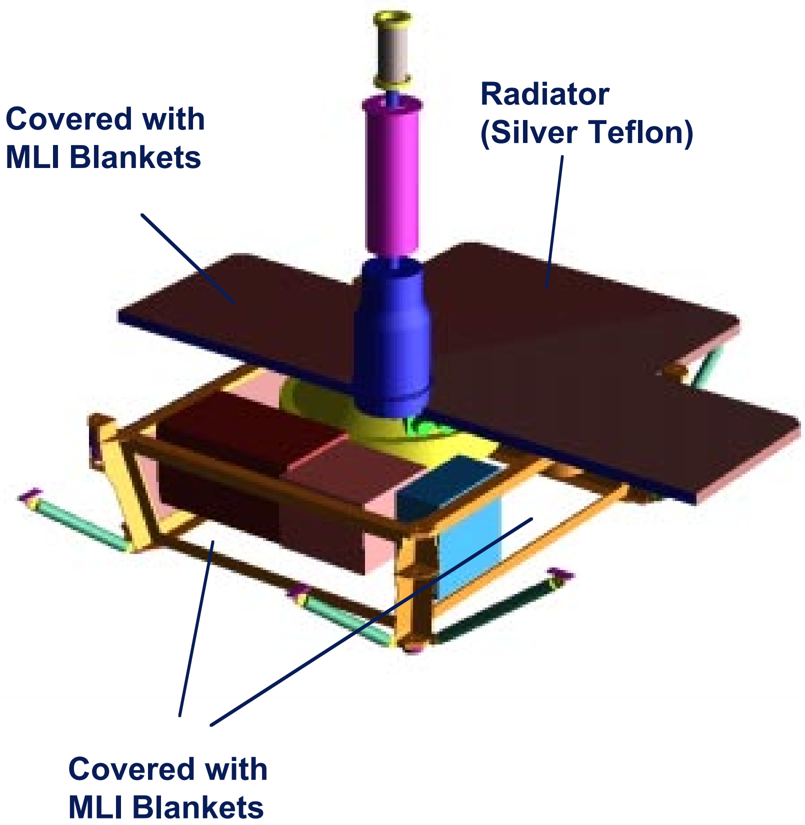
- Feedbench
  - 10 Layer MLI Blankets Cover All Sides, Top, and Bottom of Feedbench Except Feedhorns Caps and Radiators
    - Minimize Heat Exchange From Feedbench to Space
    - Minimize Feedbench Structure ΔTs
  - One Panel Designated As Radiator for LNAs
  - Radiator Is Coated With 10 Mil Silver Teflon Tape

Thermal Design Summary (4 of 8)



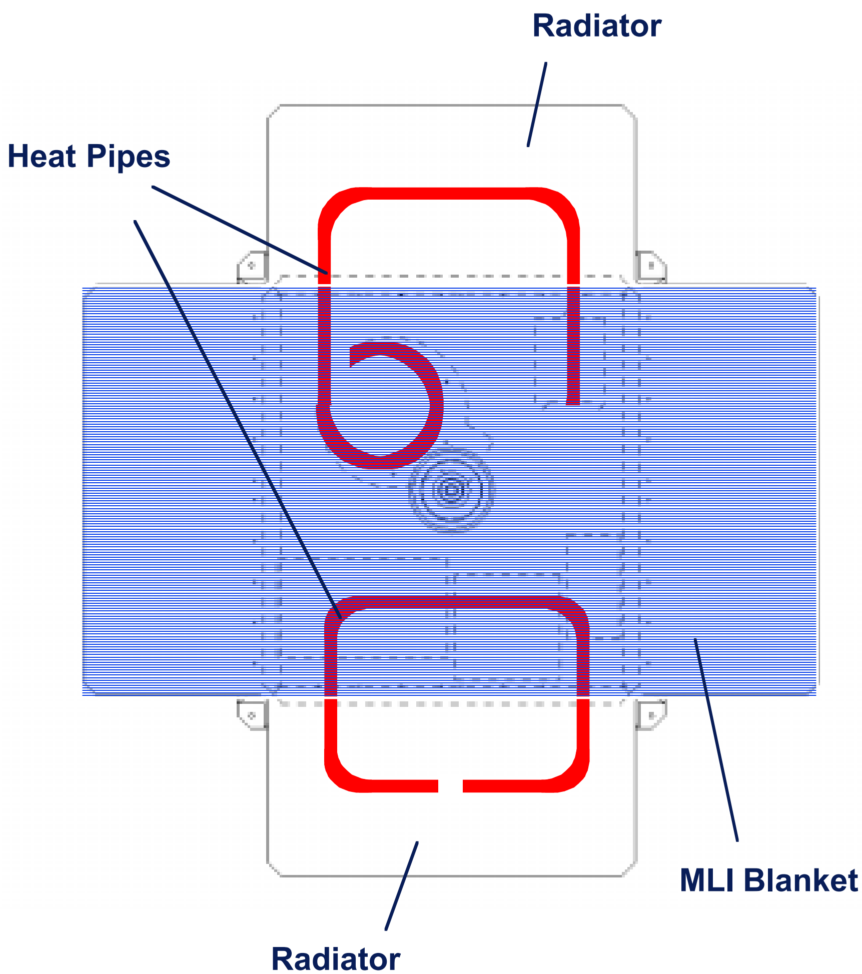
- **Feedbench (Cont.)**
  - **Copper/water Micro Heat Pipes Are Employed to Transfer Heat From LNAs to the Radiators**
    - **1/8” OD, 10” Long**
    - **Gravity Insensitive (Ground Testable and Operational in Spinning Mode)**
    - **Transport Limit: 10 W-in @20°C**
  - **Employ System Thermal Mass to Maintain ΔT/Δtime Requirement**
  - **Thermostatically Controlled Survival Heaters (~40W Total) Attached to Radiators to Keep LNAs Above -20°C**

Thermal Design Summary (5 of 8)



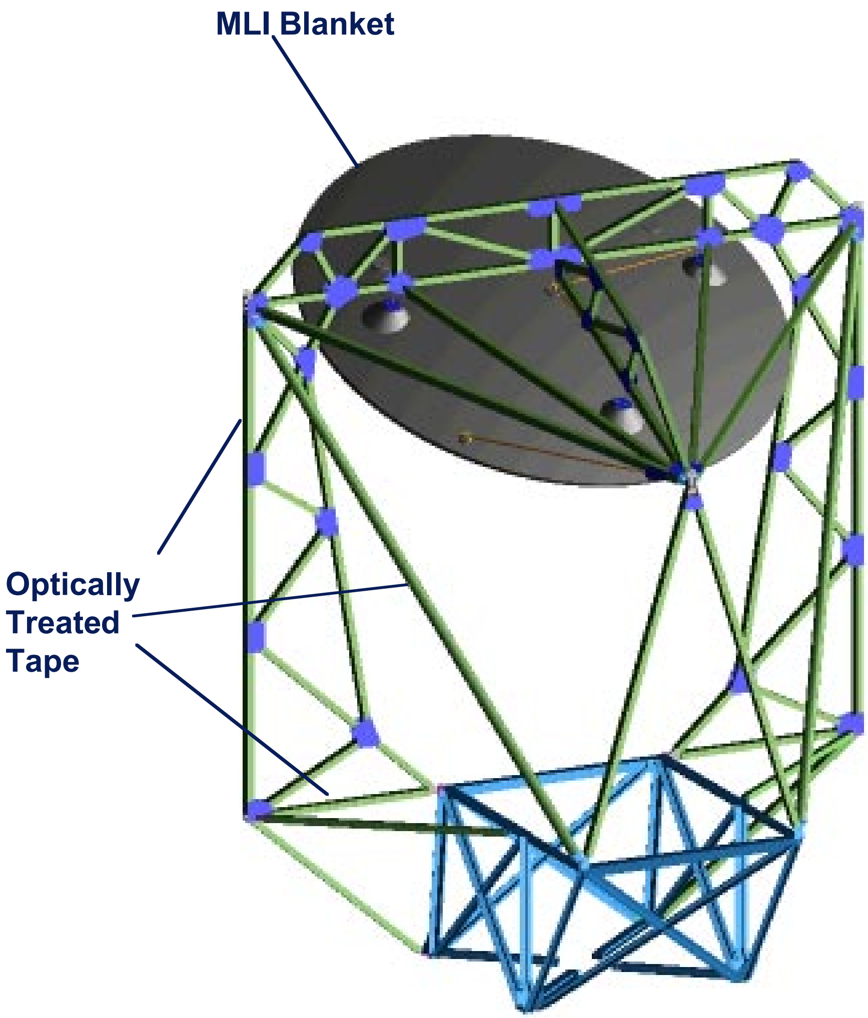
- Stationary Deck
  - 10 Layer MLI Blankets Top and Bottom of Stationary Deck Except Radiator Areas
    - Minimize Heat Exchange Between Stationary Deck, Rotating Canister, and Spacecraft
    - Minimize Canister Orbital and Seasonal Temperature Variations
  - 10 Mil Silver Teflon Coating on All Radiator Surfaces

Thermal Design Summary (6 of 8)



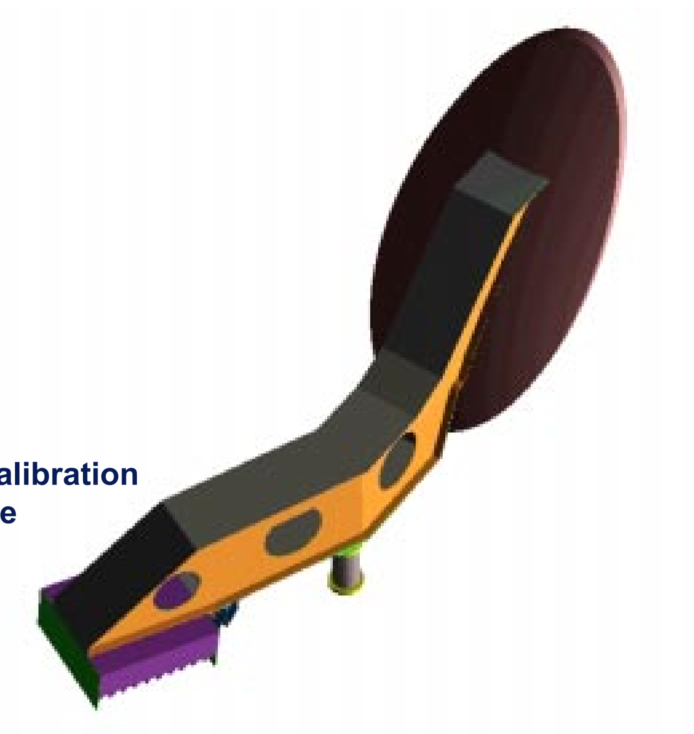
- Stationary Deck (Cont.)
  - Two (2) Aluminum/ammonia Heat Pipes Used to Transport Heat From Electronic Boxes to Radiators
    - 5/8" OD
    - Transport Limit: 10,000 W-in
    - Co-planar Heat Pipe Layout to Facilitate Ground Testing
  - Thermostatically Controlled Survival Heaters (~100W Total) Attached to Individual Boxes to Keep Above Survival Temperatures

Thermal Design Summary (7 of 8)



- **Main Reflector and Support Bench**
  - **10 Layer MLI Covering Will Encase Support Bench and Backside of Reflector**
    - **Minimize Front to Back Facesheet ΔT**
    - **Minimize Reflector to Truss ΔT**
- **Main Reflector Support Structure**
  - **All Struts Coated With Optically Treated Tape (Silicon Oxide, VDA, Kapton)**
    - **Optical Properties (α~0.15 and ε~0.15) Must Be Repeatable Within Tight Tolerance**

Thermal Design Summary (8 of 8)



- Hot Calibration Source
  - 10 Layer MLI Covering Back and Sides of Source
  - 5 W Heater Mounted to Backside
- Cold Sky Reflector
  - 10 Layer MLI Cover on Back

Design Parameter Summary (1 of 3)

PAYLOAD COMPONENT	BETA ANGLE	FLUXES	Silver Teflon α / ε	MLI EFF ε*
ROTATING CANISTER ELECTRONICS				
- Worst Hot	57.8	Hot	0.20 / 0.83	0.006
- Worst Cold	87.0	Cold	0.10 / 0.83	0.03
- Maximum $\Delta T/\Delta t$	57.8	Hot	0.20 / 0.83	0.03
FEEDBENCH				
- Worst Hot	87.0	Hot	0.20 / 0.83	0.006
- Worst Cold	57.8	Cold	0.10 / 0.83	0.03
- Maximum $\Delta T/\Delta t$	57.8	Hot	0.20 / 0.83	0.03
STATIONARY DECK				
- Worst Hot	57.8	Hot	0.20 / 0.83	0.006
- Worst Cold	87.0	Cold	0.10 / 0.83	0.03

Design Parameter Summary (2 of 3)

PASSIVE ELEMENTS	BETA ANGLE	FLUXES	α / ε	MLI EFF ε*
Main Reflector:				
- Hot Case	63	Hot	0.15 / 0.05	0.006
- Cold Case	87	Cold	0.10 / 0.05	0.03
- Maximum ΔT	87	Hot	0.15 / 0.05	0.006
- Maximum Reflector / Bench ΔT	63	Hot	0.15 / 0.05	0.03
Support Structure:				
- Hot Case	87	Hot	0.15 / 0.15	N/A
- Cold Case	57.8	Cold	0.15 / 0.15	N/A
- Maximum ΔT	57.8	Hot	0.15 / 0.15	N/A
- Maximum ΔT/Δt	57.8	Hot	0.15 / 0.15	N/A
Hot Calibration Source:				
- Hot Case	57.8	Hot	0.99 / 0.99	0.006
- Cold Case	87	Cold	0.99 / 0.99	0.03
- Maximum ΔT/Δt	57.8	Hot	0.99 / 0.99	0.03
Cold Sky Reflector:				
- Hot Case	57.8	Hot	0.15 / 0.05	0.006
- Cold Case	87	Cold	0.10 / 0.05	0.03
- Maximum ΔT	87	Hot	0.15 / 0.05	0.006

Design Parameter Summary (3 of 3)

- Other Design Parameters
  - Environmental Flux Definition

	Solar (UV)	Albedo (UV)	Earth IR
Hot	1419 W/m^2	0.28	237 W/m^2
Cold	1287 W/m^2	0.32	215 W/m^2

  - Beta Angle: 57.8° to 87°
  - Reflector Support Structure Contact Conductance: Low and High Extremes Use As Defined Below:
    - High Conductance: Adhesive K= 0.331 W/m-k, 0.005” Thick
    - Low Conductance: Adhesive K= 0.188 W/m-k, 0.015” Thick

Thermal Analysis Summary (1 of 2)

- **TCS Meets All Temperature and Stability Requirements**

COMPONENTS	REQUIREMENTS	PREDICTED PERFORMANCE
RF Electronics (Rotating Side)		
- Operational Temperature Range	0 to 40 °C	14.0 to 29.0 °C
- Non-Operational Temperature Range	-20 to 60 °C	-20 to 20 °C
- Temperature Stability	< ±0.005 °C/sec	< ±0.004 °C/sec
- Orbital Temperature Variation (No Ellipse Seasons)	< ±1.0 °C/orbit	< ±0.5 °C/orbit
- Orbital Temperature Variation (Ellipse Seasons)	< ±2.0 °C/orbit	< ±2.0 °C/orbit
LNAs (Feedbench)		
- Operational Temperature Range	0 to 40 °C	12.5 to 26.0 °C
- Non-Operational Temperature Range	-20 to 60 °C	-20 to 20 °C
- Temperature Stability	< ±0.005 °C/sec	< ±0.004 °C/sec
- Orbital Temperature Variation (No Ellipse Seasons)	< ±1.0 °C/orbit	< ±0.5 °C/orbit
- Orbital Temperature Variation (Ellipse Seasons)	< ±2.0 °C/orbit	< ±1.5 °C/orbit
Stationary Deck Electronics and Spacecraft Interface		
- Operational Temperature Range	0 to 40 °C	12.0 to 27.0 °C
- Non-Operational Temperature Range	-20 to 60 °C	-20 to 20 °C

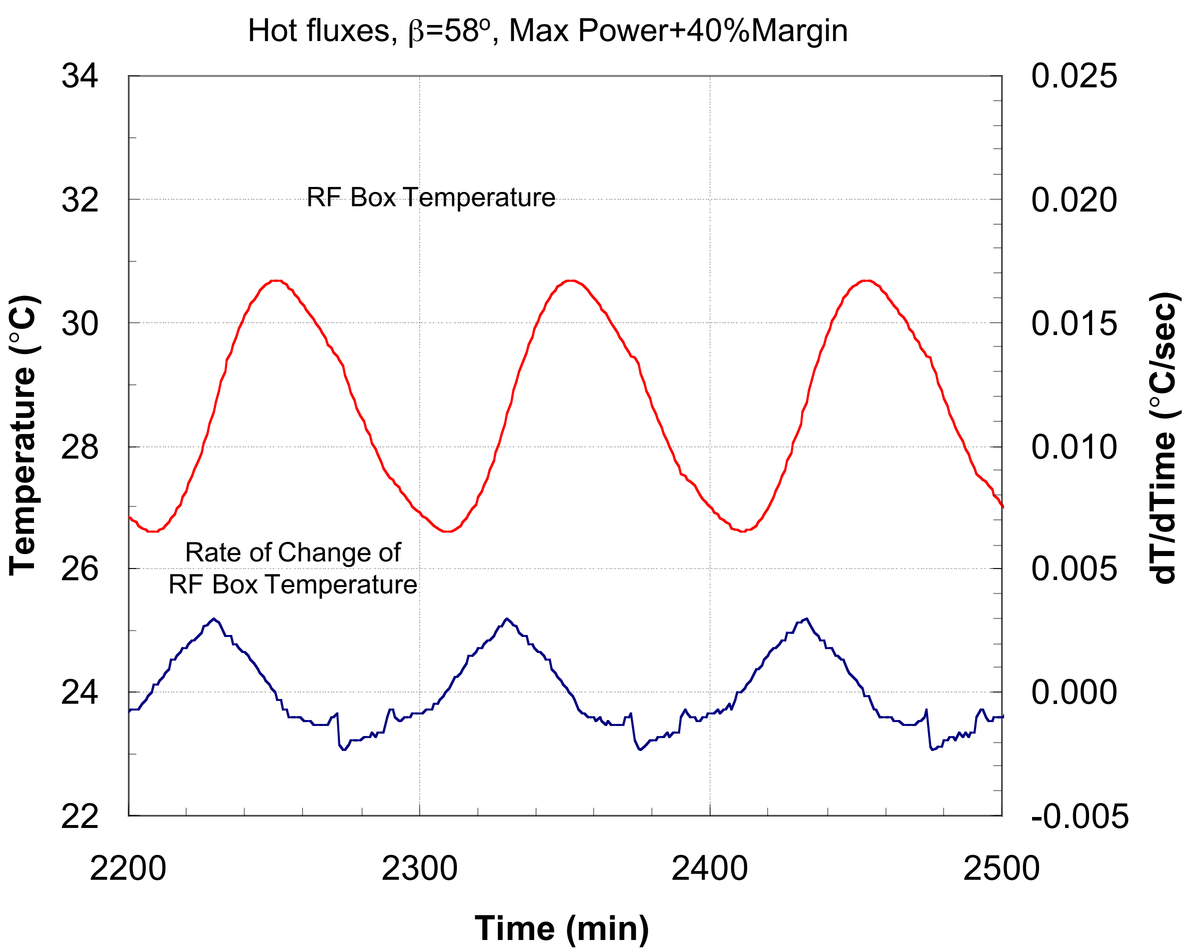
Thermal Analysis Summary (2 of 2)

COMPONENTS	REQUIREMENTS	TCS DESIGN PERFORMANCE
Main Reflector		
- Operational Temperature Range	-70 to 140 °C	-4 to 110°C
- Non-Operational Temperature Range	-70 to 140 °C	-60 to 140°C (within 30 minutes in worst hot attitude)
- Operational Facesheet Lateral ΔT	< 55 °C	< 45°C
- Front to Back Facesheet ΔT	< 5.5 °C	< 3°C
Reflector Support Structure		
- Operational Temperature Range	-50 to 70 °C	-10 to 30°C
- Non-Operational Temperature Range	-50 to 70 °C	-50°C to 60 °C (within 90 minutes of worst cold attitude)
- ΔT (Opposing Members)	< 20°C	< 1°C
- ΔT (Front to Back)	< 20 °C	< 10°C
Hot Calibration Source		
- Temperature Range	250 to 330 K	265 to 315 K
- ΔT Across "Aperture"	< 0.1 °C	< 0.1 °C
- ΔT/Δt	0.05 °C/sec	< 0.05 °C/sec

Thermal Analysis Results (Rotating Canister Electronics)

ROTATING CANISTER WORST HOT CASE TRANSIENT ANALYSIS

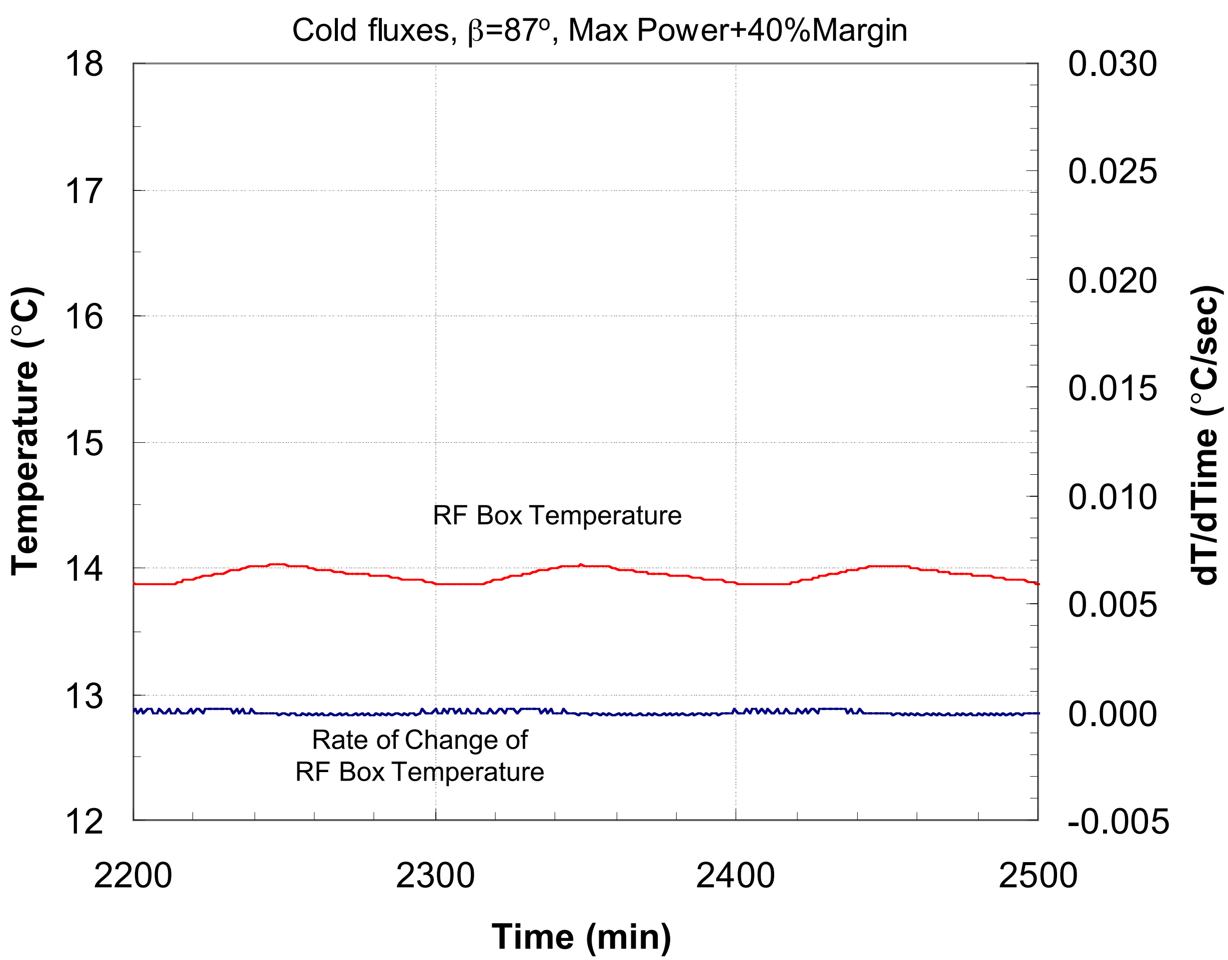
Eclipse Season



Thermal Analysis Results (Rotating Canister Electronics)

ROTATING CANISTER WORST COLD CASE TRANSIENT ANALYSIS

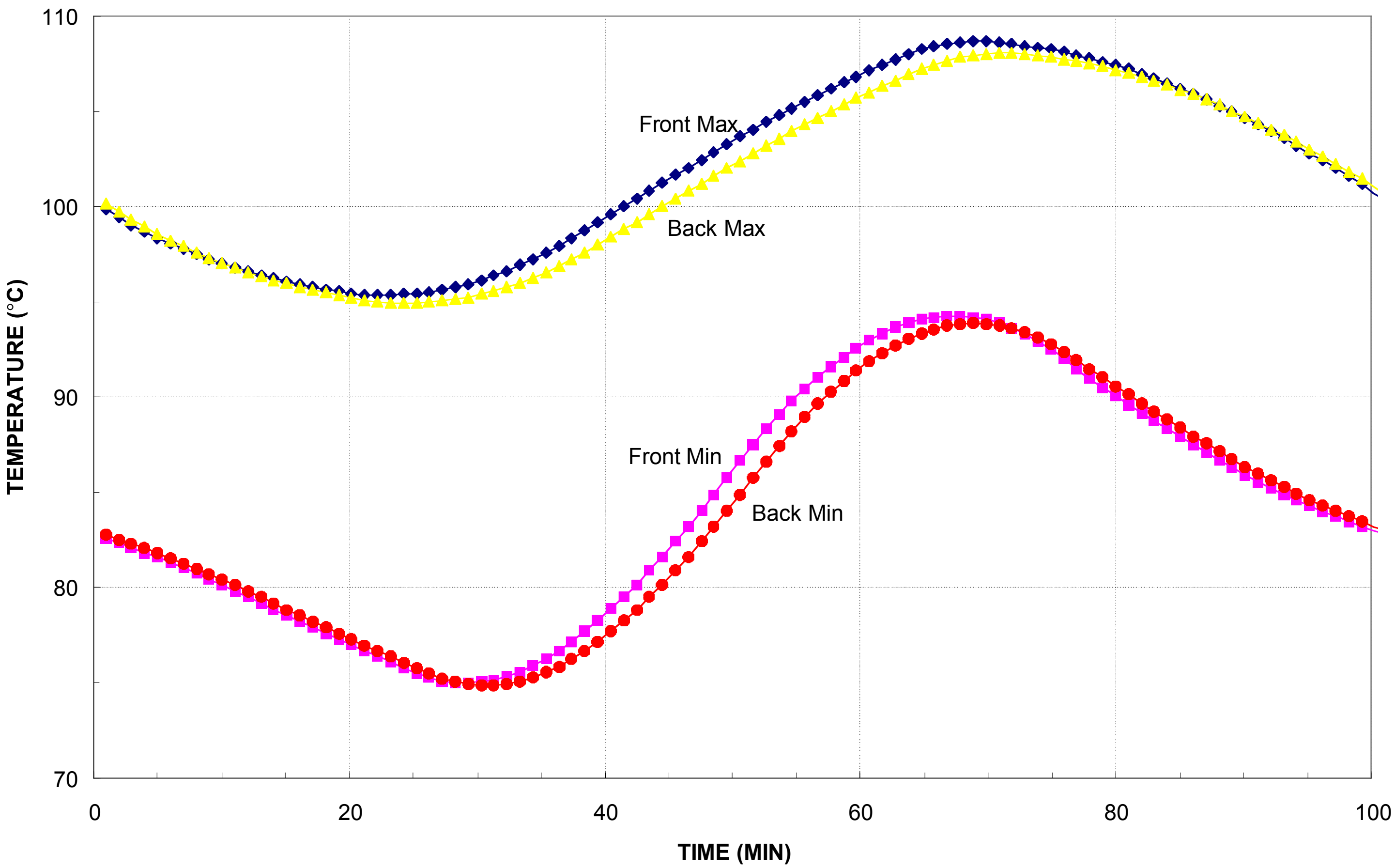
Non-Eclipse Season



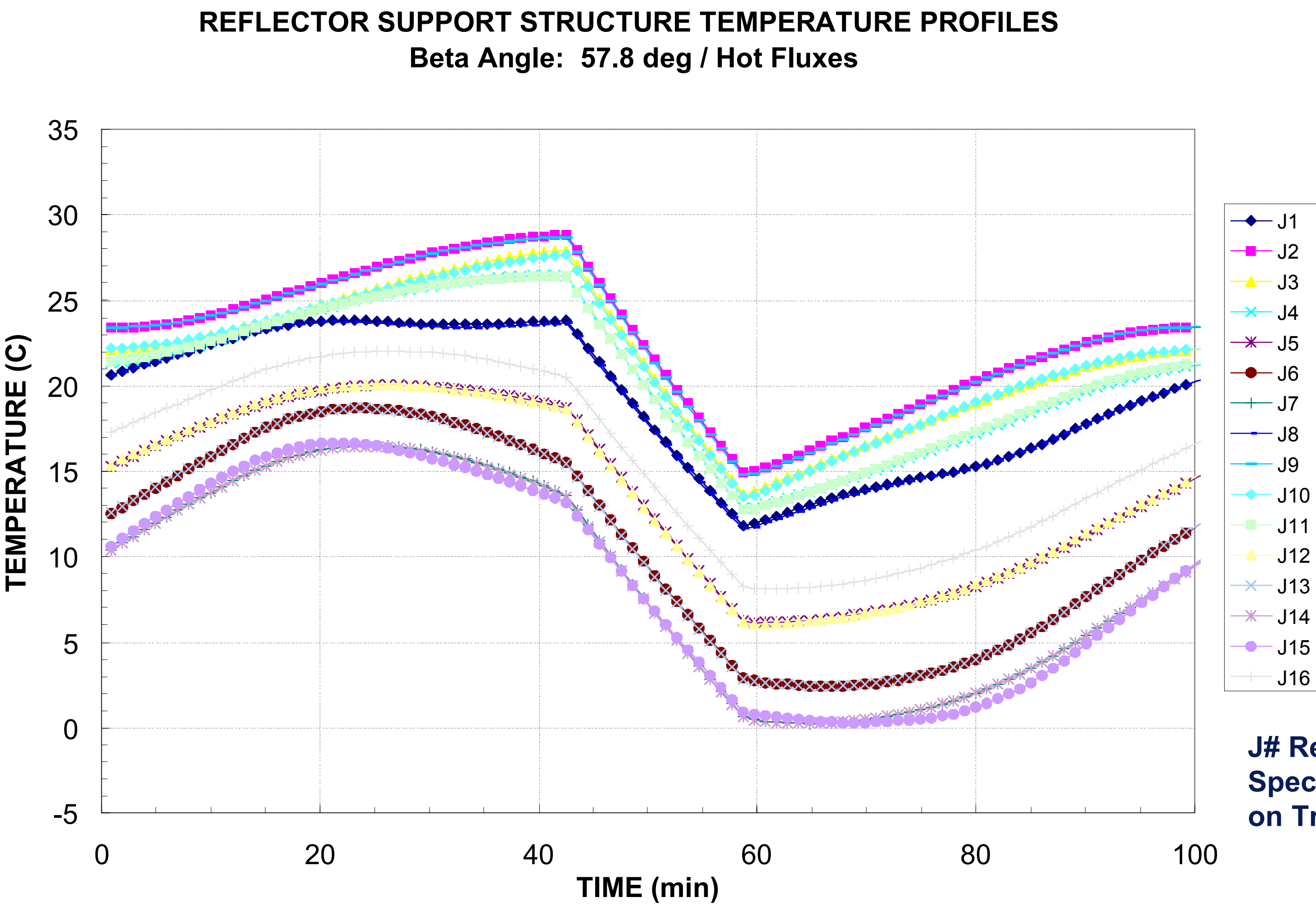
Thermal Analysis Results (Reflector)

REFLECTOR HOT CASE ΔT TRANSIENT ANALYSIS

MAIN REFLECTOR MAXIMUM / MINIMUM TEMPERATURE PROFILES
Beta Angle: 63 deg / Hot Fluxes / 0.006 MLI ε*



Thermal Analysis Results
(Reflector Support Structure)



J# Refers to Specific Locations on Truss

Long-lead Items

- Thermostats - 10 Months Lead Time
- Heat Pipes - 12 Months Lead Time
- MLI Blankets - 6 Months Lead Time
- Silver Teflon Tape - 6 Months Lead Time
- Optically Treated Tapes - 6 Months

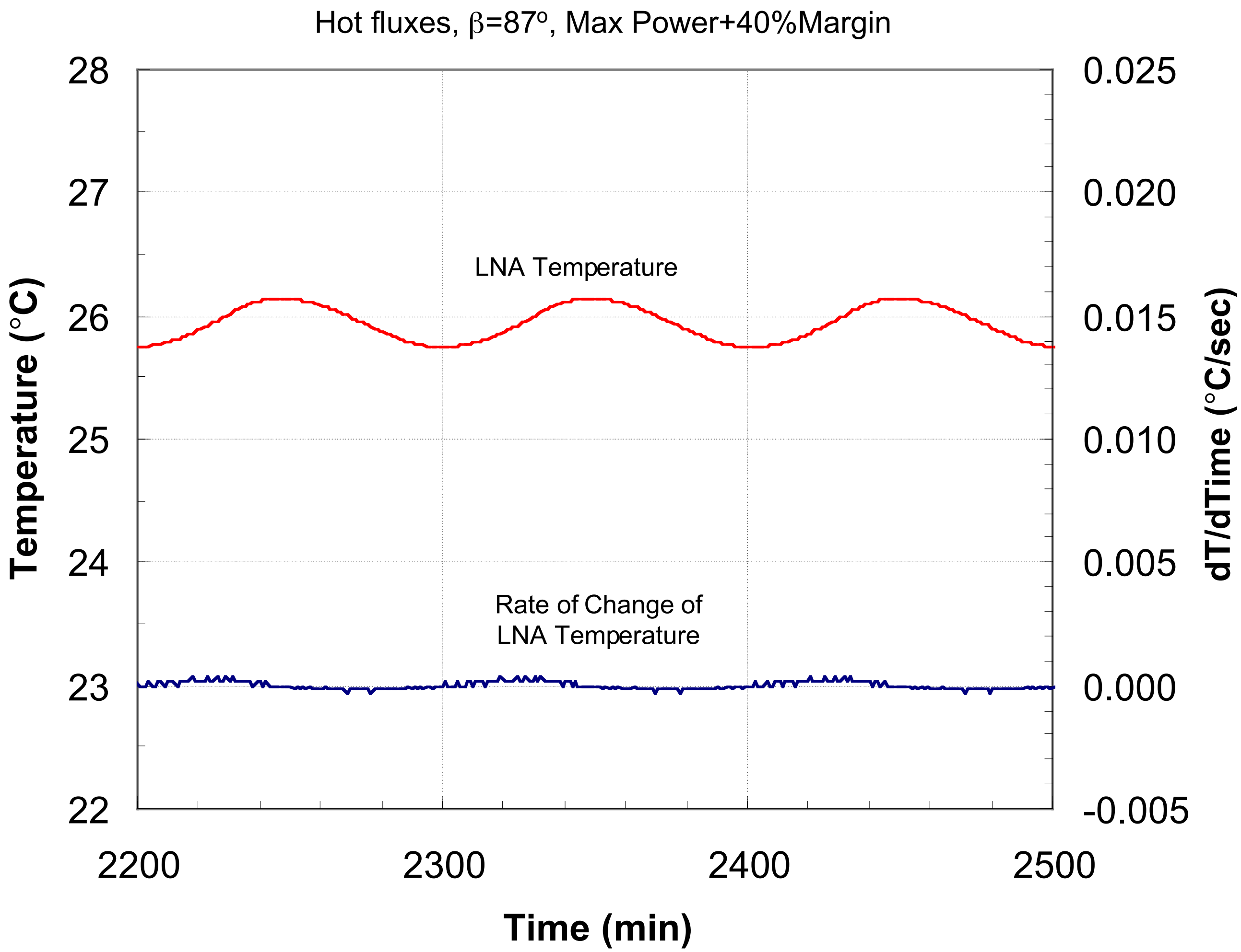
Testing

- Structure Joint Conductance Tests
- Micro Heat Pipes Performance Tests
- Heat Pipe System Performance Tests (Performed on Mechanical EBB)
- Thermal Design Verification Test

Thermal Control Subsystem
(backup)

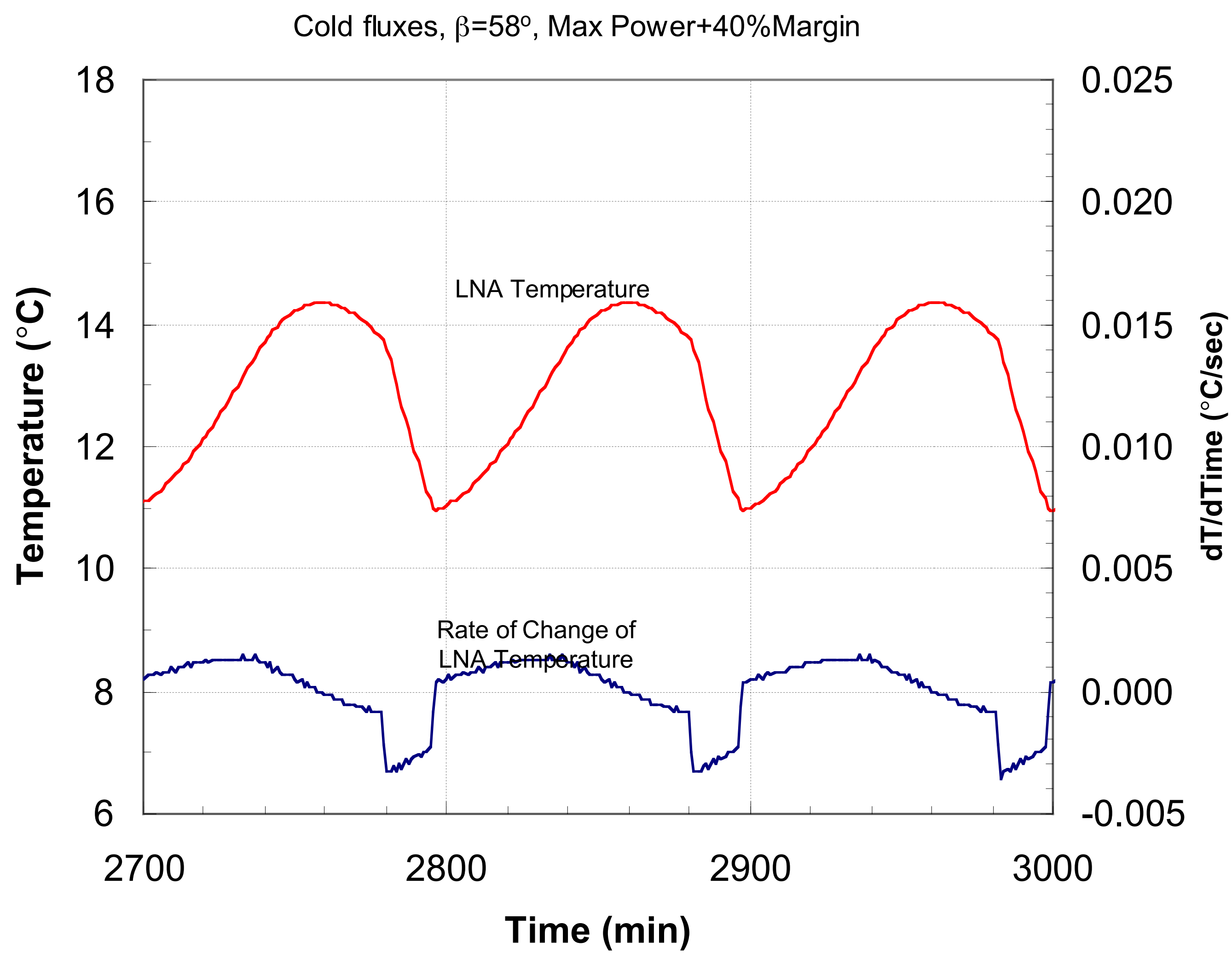
Thermal Analysis

Feedbench Worst Hot Case Transient Analysis



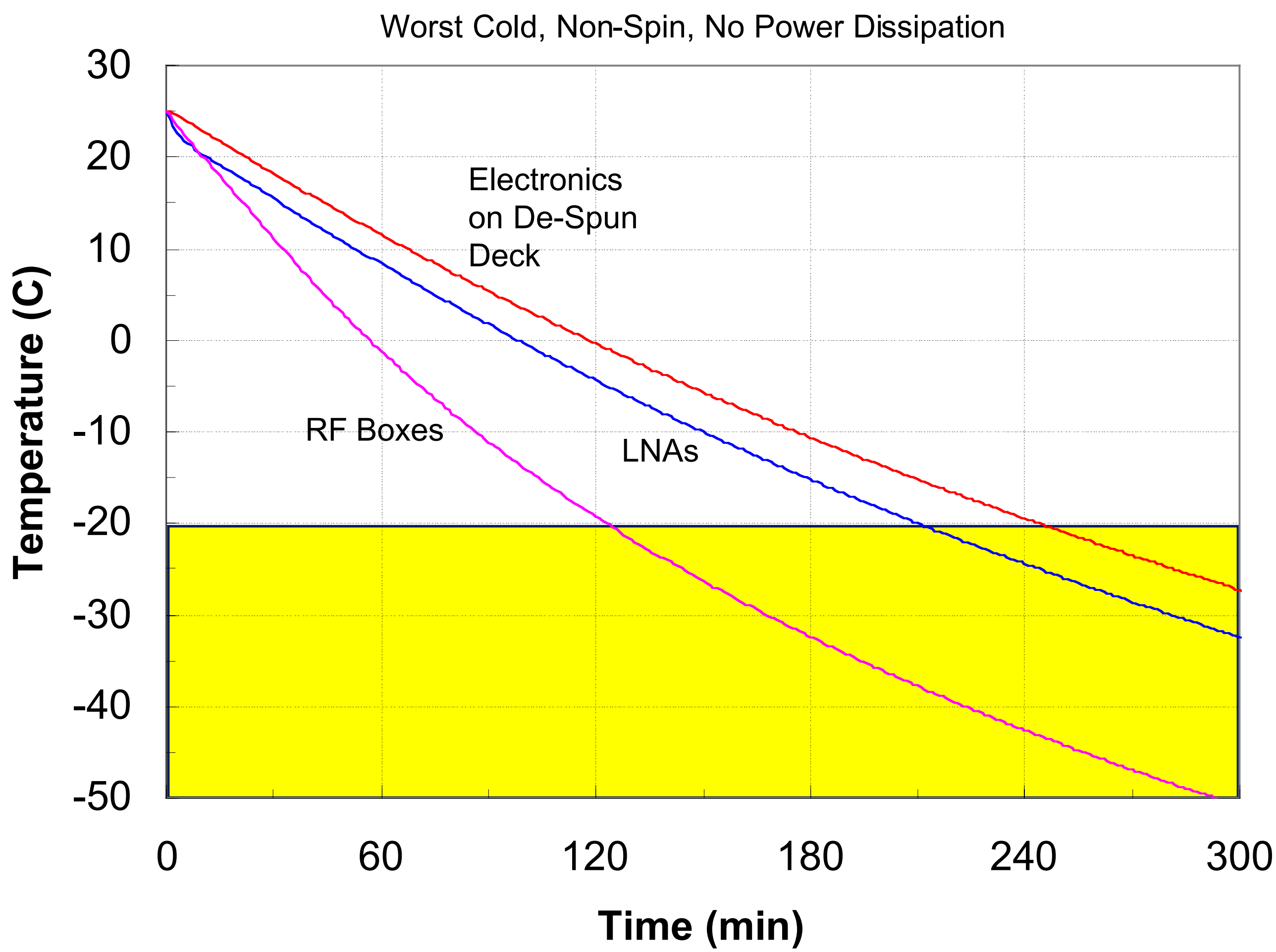
Thermal Analysis

Feedbench Worst Cold Case Transient Analysis



Thermal Analysis

NON-OPERATIONAL MODE COOL DOWN TRANSIENT ANALYSIS



Thermal Design And Analysis

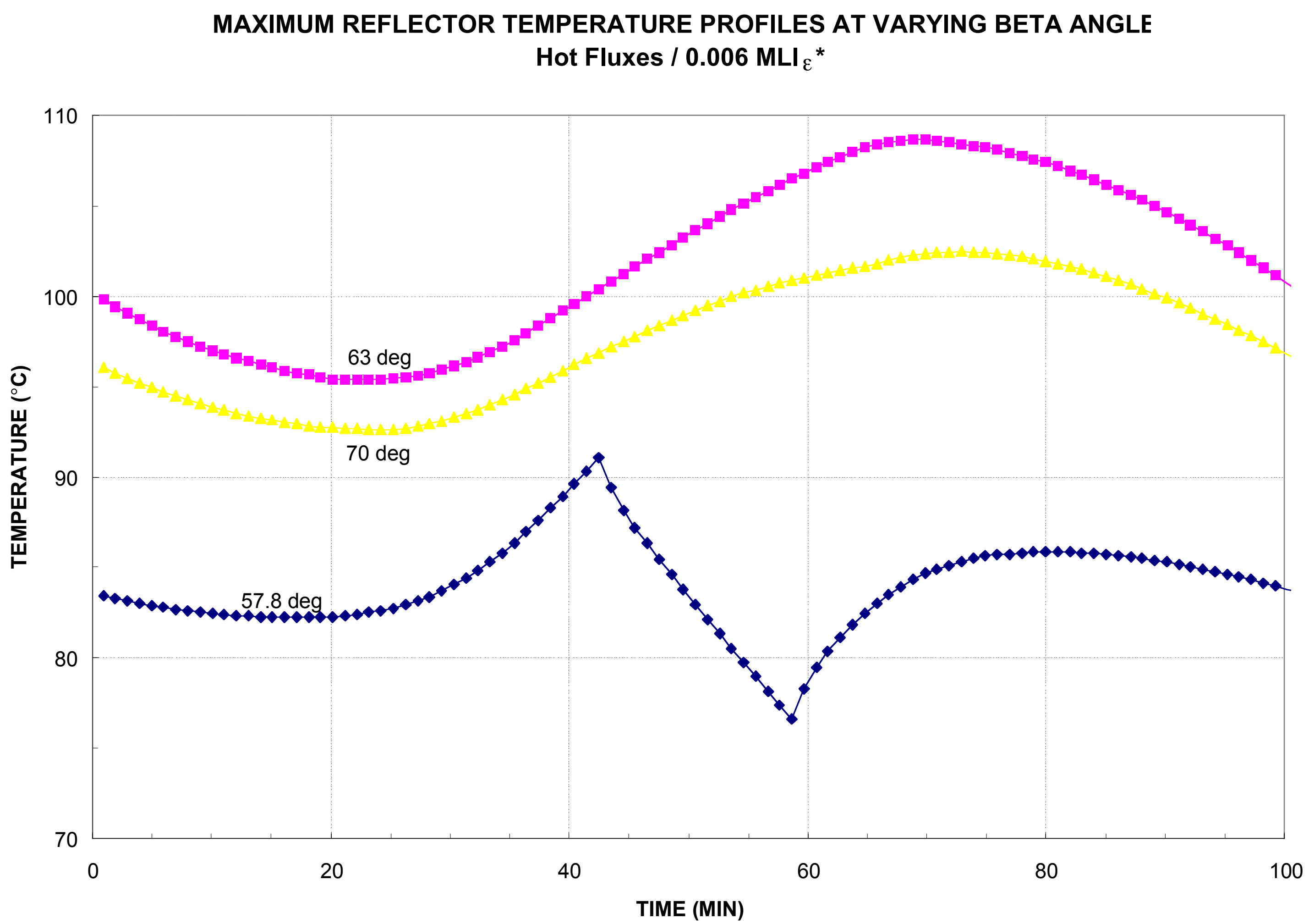
REFLECTOR STEADY STATE ANALYSIS

- Cases with 90° Beta Angle are Steady State
  - Fluxes are spin averaged
  - Constant Dissipation

CASES	FRONT MAX T	FRONT MIN T	LATERAL Δ T	BACK MAX T	BACK MIN T	FRONT TO BACK Δ T
Cold Case	25.4	-3.1	28.5	25.3	-3.1	0.1
Maximum Lateral ΔT	85.5	42.2	43.3	85.4	42.2	0.1

  - Maximum DT case:
    - Maximum temperature node: 50009
    - Minimum temperature node: 50099

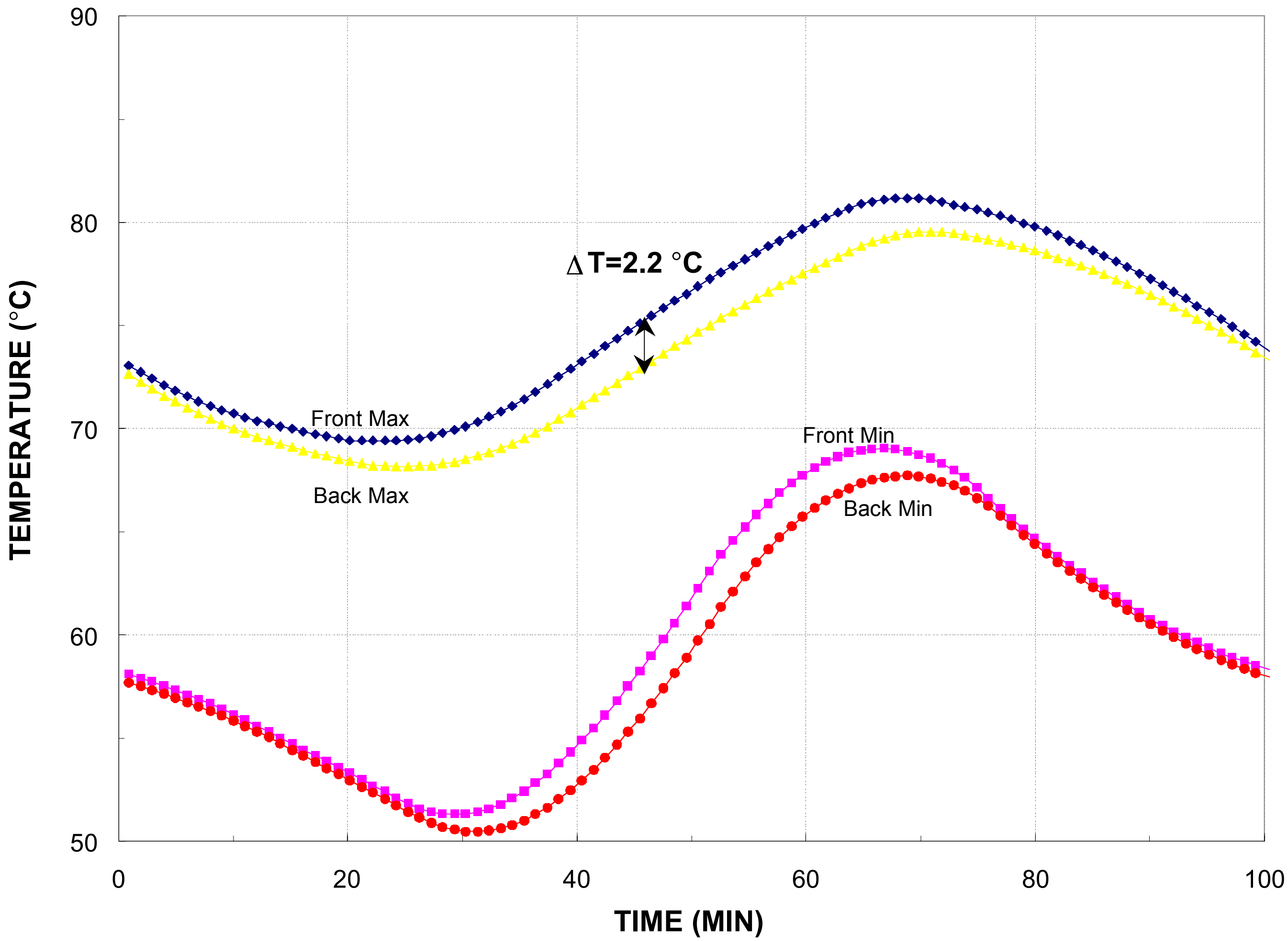
Thermal Analysis (Reflector)



Thermal Analysis (Reflector)

REFLECTOR HOT CASE MAXIMUM FRONT/BACK ΔT

Beta Angle: 63 deg / Hot Fluxes / 0.03 MLI ε*



Thermal Analysis (Truss)

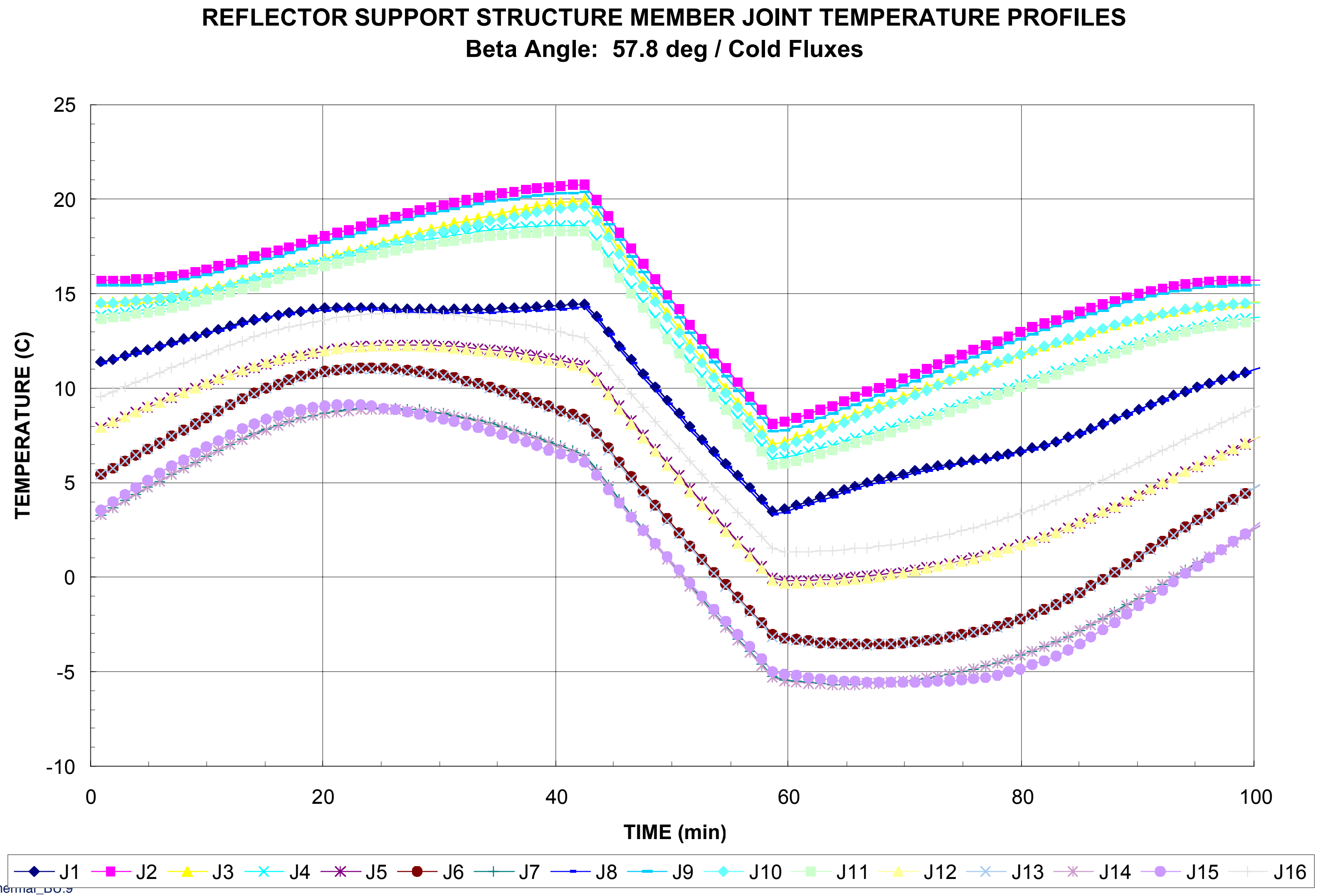
REFLECTOR SUPPORT STRUCTURE
HOT CASE STEADY STATE

- All Structure Member Joint Temperatures Below Requirement
- ΔT Between Members Greater for Low k Adhesive Bond
  - All transient analysis will be performed with low k adhesive: worst ΔT, and $\Delta T/\Delta t$

JOINT NUMBER	TEMPERATURE (°C)
1	15.3
2	18.1
3	20.3
4	14.6
5	8.8
6	1.3
7	-0.4
8	15.3
9	17.6
10	20.3
11	13.8
12	8.6
13	1.2
14	-0.5
15	-1.6
16	10.1

Thermal Analysis (Truss)

- All Structure Member Joint Temperatures Above Requirement



Thermal Analysis (Truss)

REFLECTOR SUPPORT STRUCTURE
MAXIMUM ΔT AND ΔT/Δt

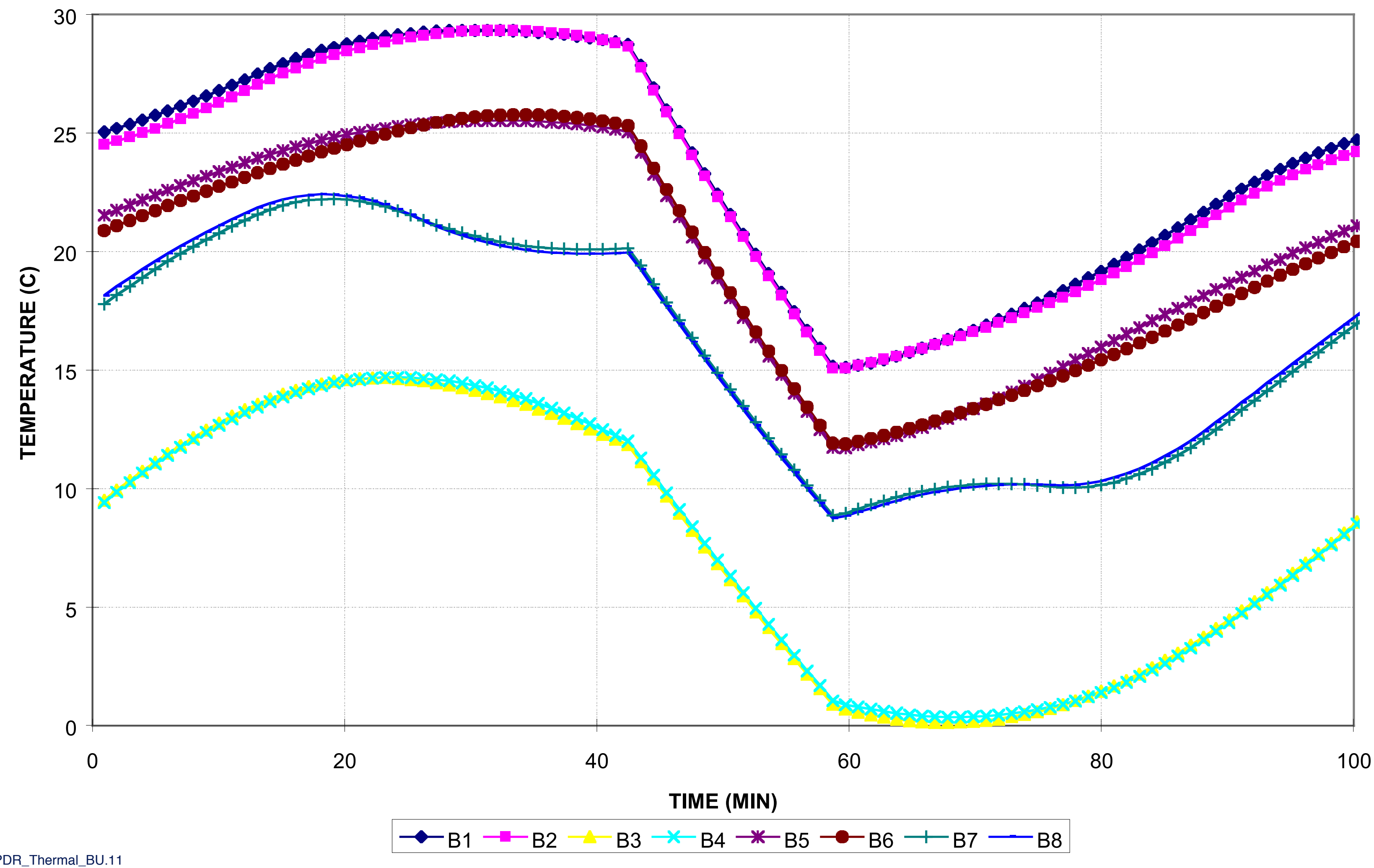
- **All Joint ΔT and ΔT/Δt Within Requirements**

Time (min)	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10	J11	J12	J13	J14	J15	J16
0.9066	20.64	23.39	22.15	21.34	15.26	12.53	10.36	20.64	23.41	22.18	21.44	15.36	12.56	10.38	10.6	17.25
5.9706	21.62	23.61	22.45	21.87	16.76	14.38	12.32	21.6	23.61	22.46	21.96	16.86	14.42	12.34	12.75	18.67
11.0406	22.6	24.27	23.09	22.71	18.08	16.21	14.09	22.57	24.25	23.08	22.78	18.19	16.24	14.11	14.63	20
16.1106	23.45	25.24	23.98	23.74	19.18	17.8	15.56	23.42	25.19	23.94	23.79	19.3	17.81	15.56	16.1	21.14
21.1806	23.82	26.21	24.91	24.64	19.82	18.6	16.35	23.76	26.15	24.82	24.68	19.91	18.59	16.32	16.65	21.82
26.2506	23.72	27.14	25.85	25.39	20.02	18.61	16.46	23.6	27.1	25.69	25.41	20.04	18.58	16.4	16.33	22.03
31.3146	23.6	27.91	26.69	25.95	19.89	18.03	16.01	23.43	27.86	26.46	25.95	19.85	17.99	15.93	15.57	21.88
36.3846	23.64	28.47	27.38	26.31	19.49	17.04	15.12	23.46	28.39	27.12	26.27	19.41	17	15.03	14.58	21.42
41.4546	23.79	28.79	27.86	26.43	18.86	15.78	13.88	23.62	28.66	27.6	26.37	18.76	15.72	13.77	13.41	20.67
46.5246	20.57	25.1	24.09	22.78	15.44	12.15	10.11	20.4	24.95	23.88	22.73	15.32	12.07	10.01	9.93	17.23
51.5886	16.7	20.65	19.53	18.44	11.45	8.12	5.97	16.54	20.49	19.33	18.38	11.34	8.05	5.89	6.03	13.3
56.6586	13.15	16.51	15.29	14.38	7.69	4.36	2.12	13	16.36	15.11	14.32	7.59	4.3	2.05	2.36	9.63
61.7286	12.37	15.46	14.34	13.23	6.16	2.58	0.31	12.22	15.3	14.15	13.18	6.09	2.58	0.3	0.6	8.09
66.7986	13.44	16.75	15.7	14.22	6.41	2.41	0.26	13.3	16.61	15.56	14.24	6.37	2.42	0.28	0.32	8.32
71.8626	14.25	18.09	17.01	15.29	6.91	2.67	0.63	14.16	17.98	16.93	15.38	6.91	2.68	0.66	0.34	8.87
76.9326	14.84	19.48	18.27	16.46	7.66	3.33	1.36	14.8	19.39	18.28	16.59	7.72	3.33	1.38	0.67	9.71
82.0026	15.64	20.77	19.45	17.68	8.74	4.52	2.53	15.66	20.72	19.51	17.82	8.85	4.51	2.54	1.66	10.87
87.0726	16.87	21.93	20.52	18.93	10.2	6.33	4.19	16.9	21.91	20.6	19.07	10.33	6.32	4.18	3.47	12.37
92.1366	18.33	22.86	21.42	20.11	11.93	8.55	6.24	18.35	22.88	21.49	20.24	12.04	8.54	6.22	5.85	14.09
97.2066	19.59	23.34	21.96	20.91	13.62	10.62	8.3	19.6	23.37	22.01	21.03	13.73	10.63	8.29	8.24	15.72
101.3826	20.47	23.4	22.13	21.28	14.97	12.2	9.99	20.46	23.42	22.17	21.39	15.07	12.22	10	10.18	16.98

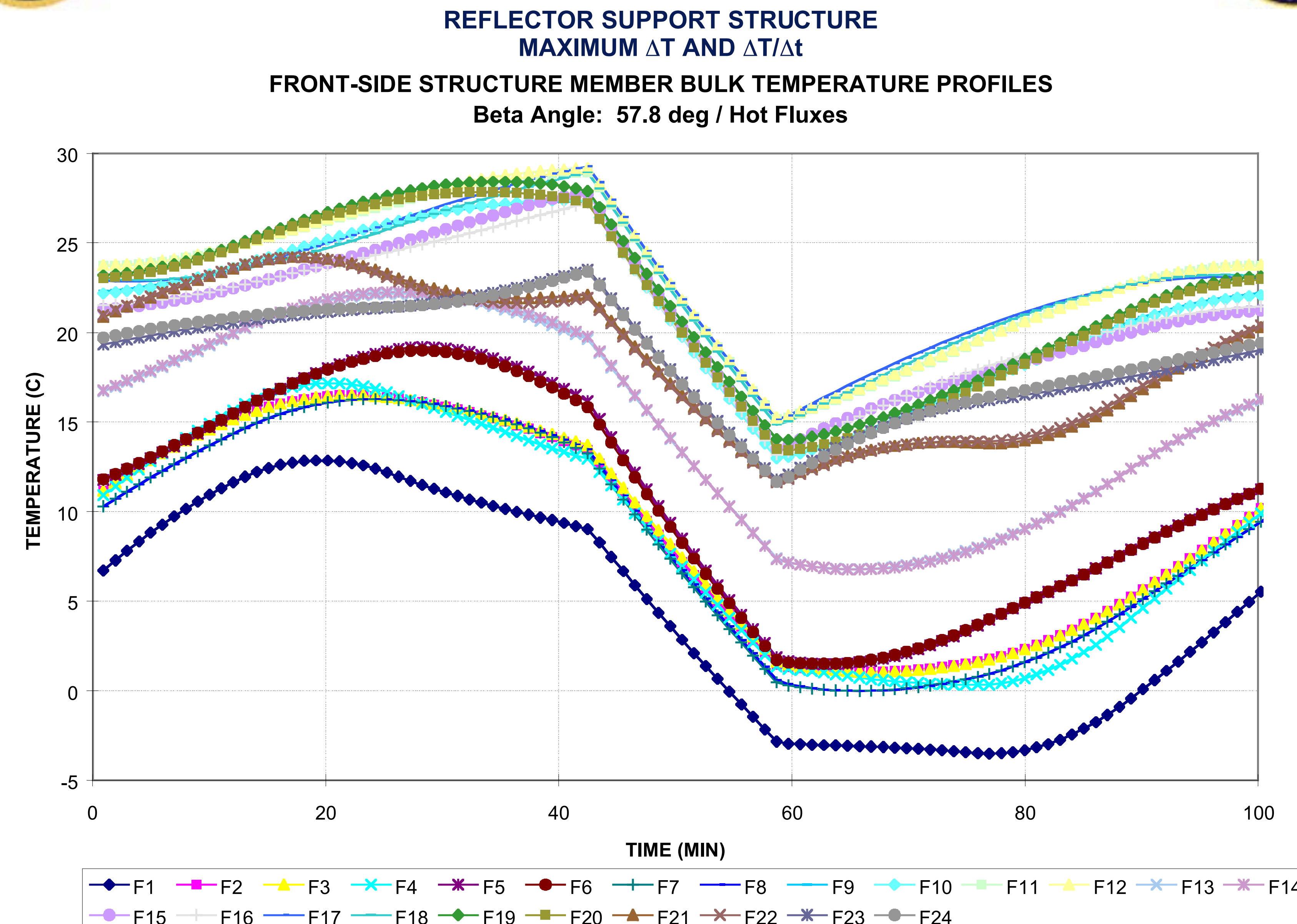
Thermal Analysis (Truss)

REFLECTOR SUPPORT STRUCTURE
MAXIMUM ΔT AND ΔT/Δt

BACK-SIDE STRUCTURE MEMBER BULK TEMPERATURE PROFILES
Beta Angle: 57.8 / Hot Fluxes

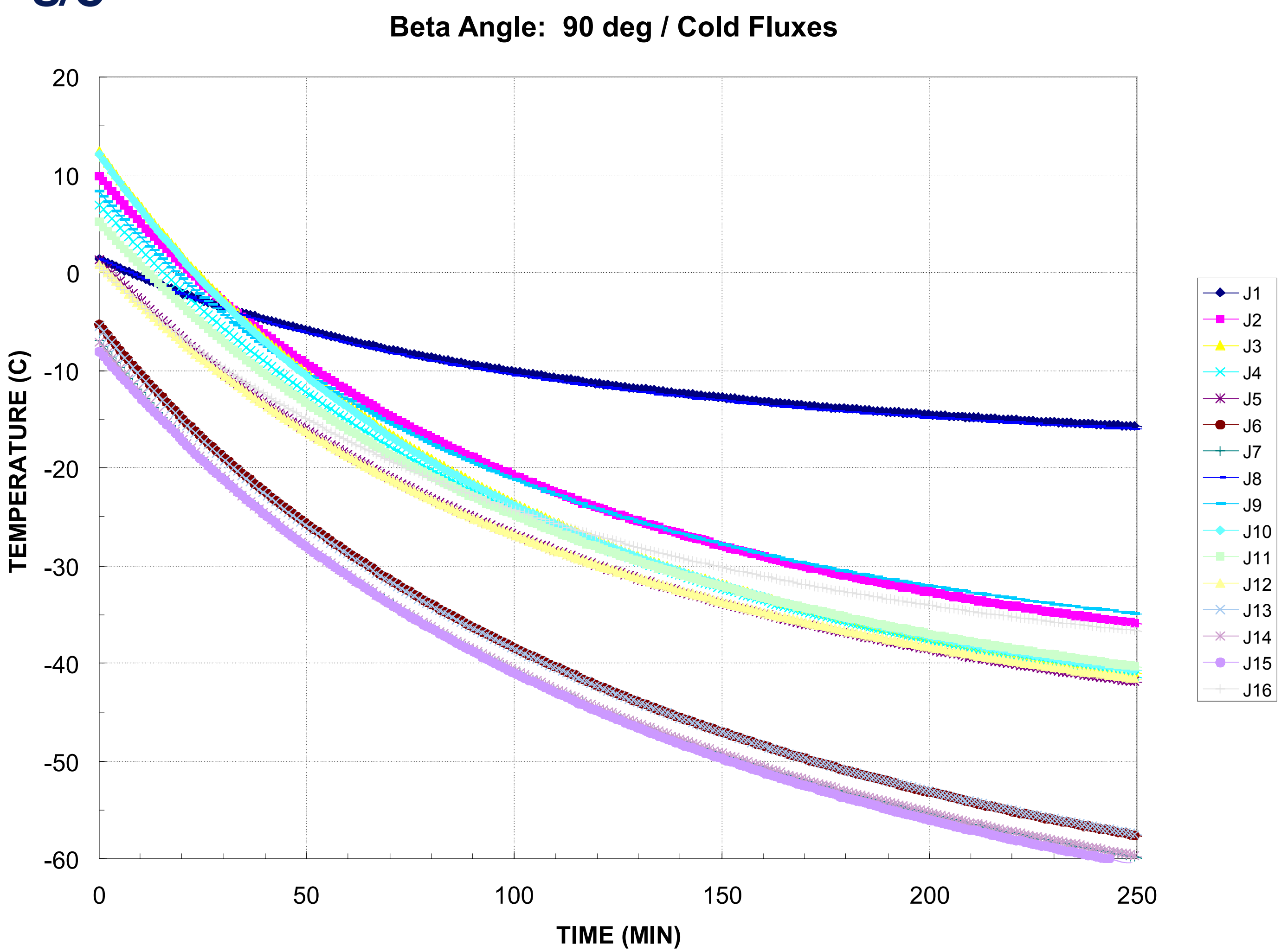


Thermal Analysis (Truss)



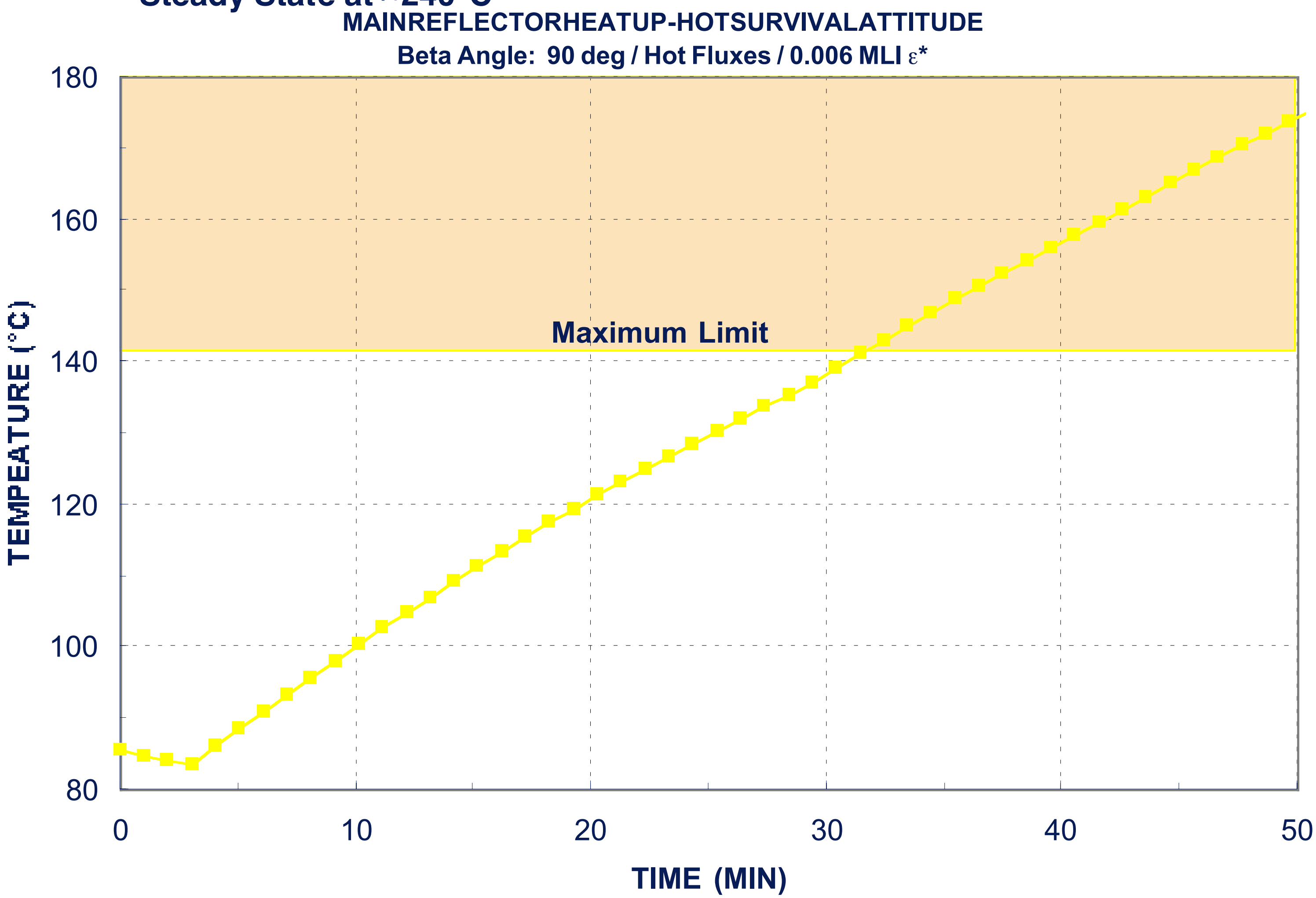
Thermal Analysis (Truss)

- **Survival and Non-Operational Mode Cold Case:**
  - **Attitude is Sun pointing in the -z axis: structure is shaded by S/C**



Thermal Analysis Results (Reflector)

- Survival and Non-Operational Mode Hot Case (Sun Normal to Reflector)
- 30 Minutes Before Exceeding Maximum Temperature Requirement (140°C)
- Steady State at ~240°C



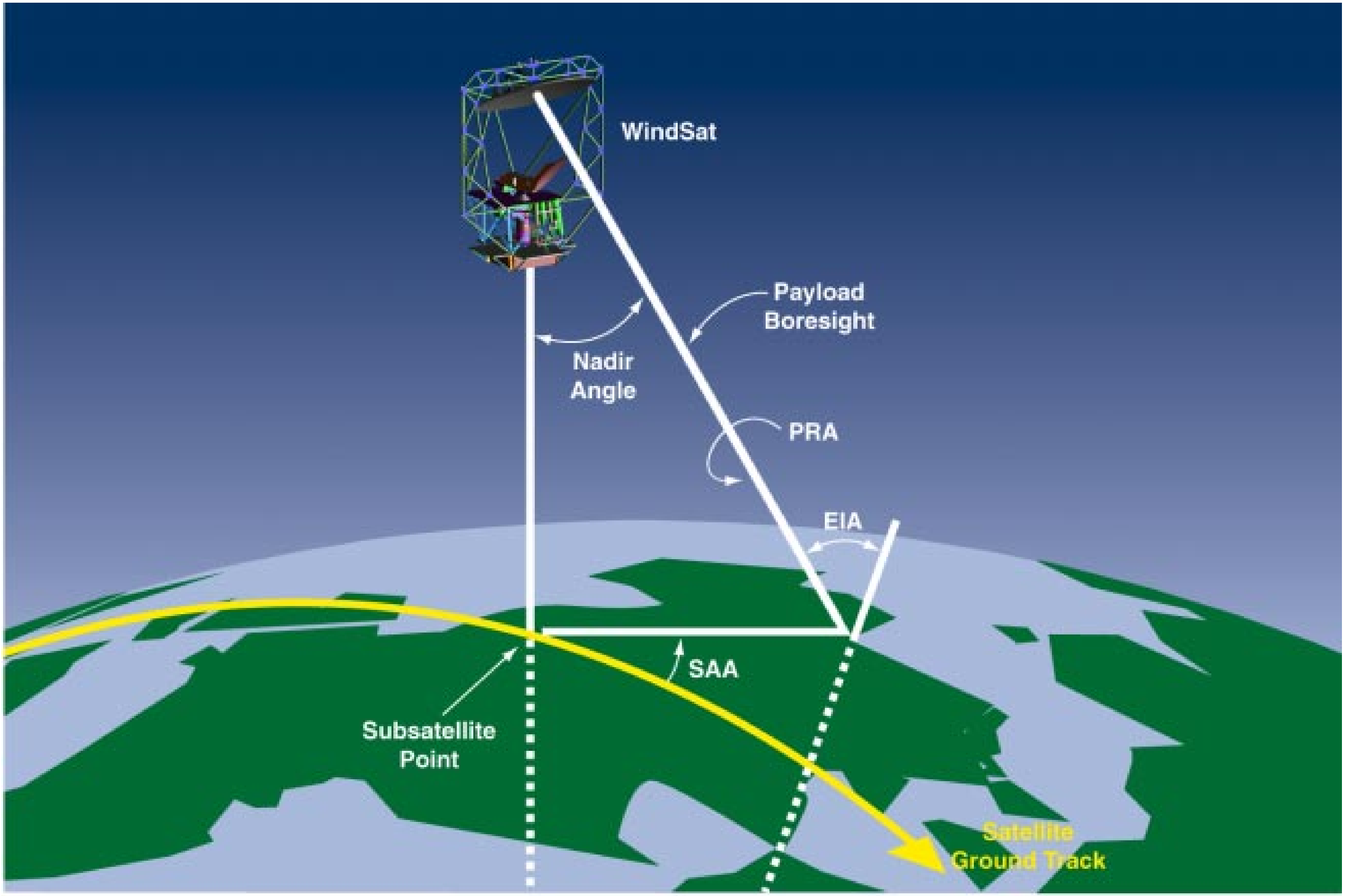
Pointing Determination and Control

M. Mook

Contents

- Top Level Requirements
- Goals, Assumptions and Derived Requirements
- Functional Block Diagram
- BAPTA/MWA Controller
- Payload Imbalance and Line-of-Sight Pointing Estimation
- Integration and Testing

Boresight Pointing



Boresight Pointing Requirements

BORESIGHT POINTING REQUIREMENTS Error Limits In Degrees (1 Sigma)				
	Knowledge		Control	
	Bias	Random	Bias	Random
EIA	0.05	0.05	1.00	0.25
PRA	0.05	0.05	1.00	1.00
SA	Derived	Derived	0.15 Total	
SAA	Derived		1.00	1.00
Geolocation	1/5 Of 37 GHz Pixel		NA	
Rate Control /Jitter	NA		1/5 Of 37 GHz Pixel Over 1 msec	

- SA Is the Scan Angle of the Spinning Section With Respect to the Despun Section; the Requirement Is Driven by the Calibration Requirements
- SAA Control Is Stated As 1 Degree but There Is No Hard Requirement

PDC Top Level Design Requirements

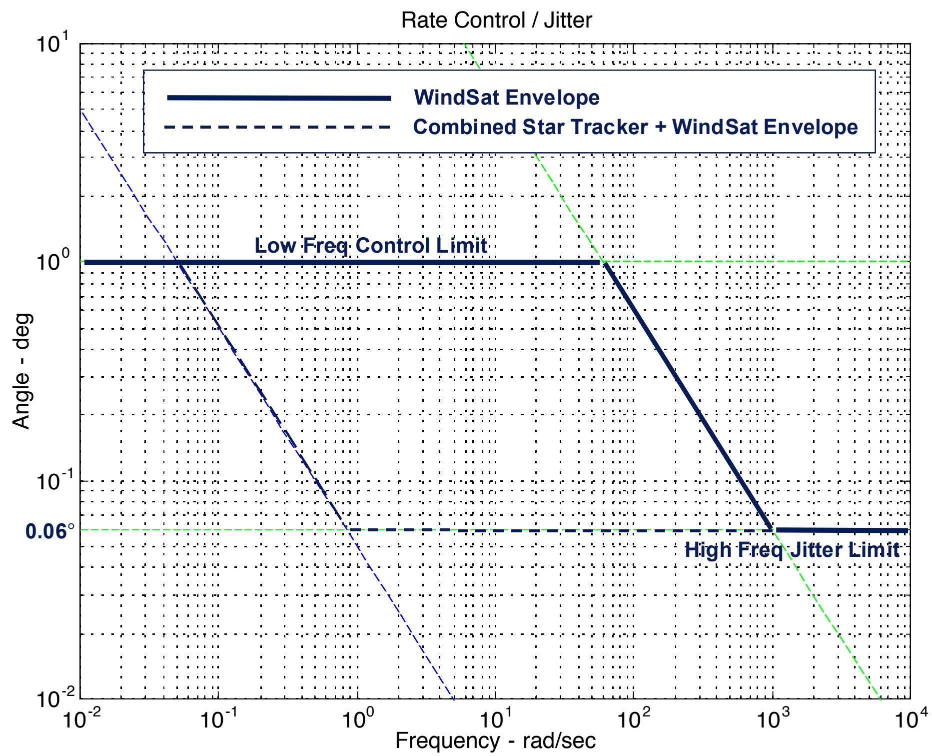
Functional Requirements

- Spacecraft
  - Initial Attitude Acquisition
  - Safe Hold Mode(s)
  - Attitude Determination and Control
  - Orbit Control
- Payload
  - PL Spin Up/Spin Down
  - PL Momentum Cancellation
  - PL Mass Balancing
  - Boresight Pointing Determination and Geolocation
  - Spacecraft Position Determination

Performance Requirements

- Spacecraft
  - Nadir Pointing (r/p,y): ±0.2°, ±0.5°
  - Stability: 0.2°/sec
  - Jitter (Over 1 msec): 0.03°
  - Attitude Knowledge: ±0.02°
  - Orbit Altitude 830±40Km
  - Orbit Inclination ±0.2°
- Payload
  - Spin Rate: 29.6RPM±0.05%
  - Residual Momentum: 2 N-m-s
  - Static Imbalance: 0.10 lbm-ft
  - Dynamic Imbalance: 2.5 lbm-ft^2
  - Pointing Knowledge: ±0.05°
  - Position Knowledge: 200 m
  - Velocity Knowledge: 0.10 m/s

Jitter Requirement



- **Jitter Amplitude vs. Frequency for Periodic Motions**
- **High Freq. Limit Is 1/5 Of 37 GHz Pixel (0.06°)**
- **Low Frequency Limit Is 1° Pointing Control Requirement**
- **Slope Is Determined By Limiting Motion to 0.06° Over the 37 GHz Integration Period (1 msec)**

Top Level Goals, Assumptions, and Derived Requirements (1 of 2)

Design Goals

- Minimize Bus/Payload Interface Complexity
- Reduce Bus Requirements (Enabling Procurement of Less Risky/Expensive Bus)
- Minimize Impact on Other Subsystems

Baseline Assumptions

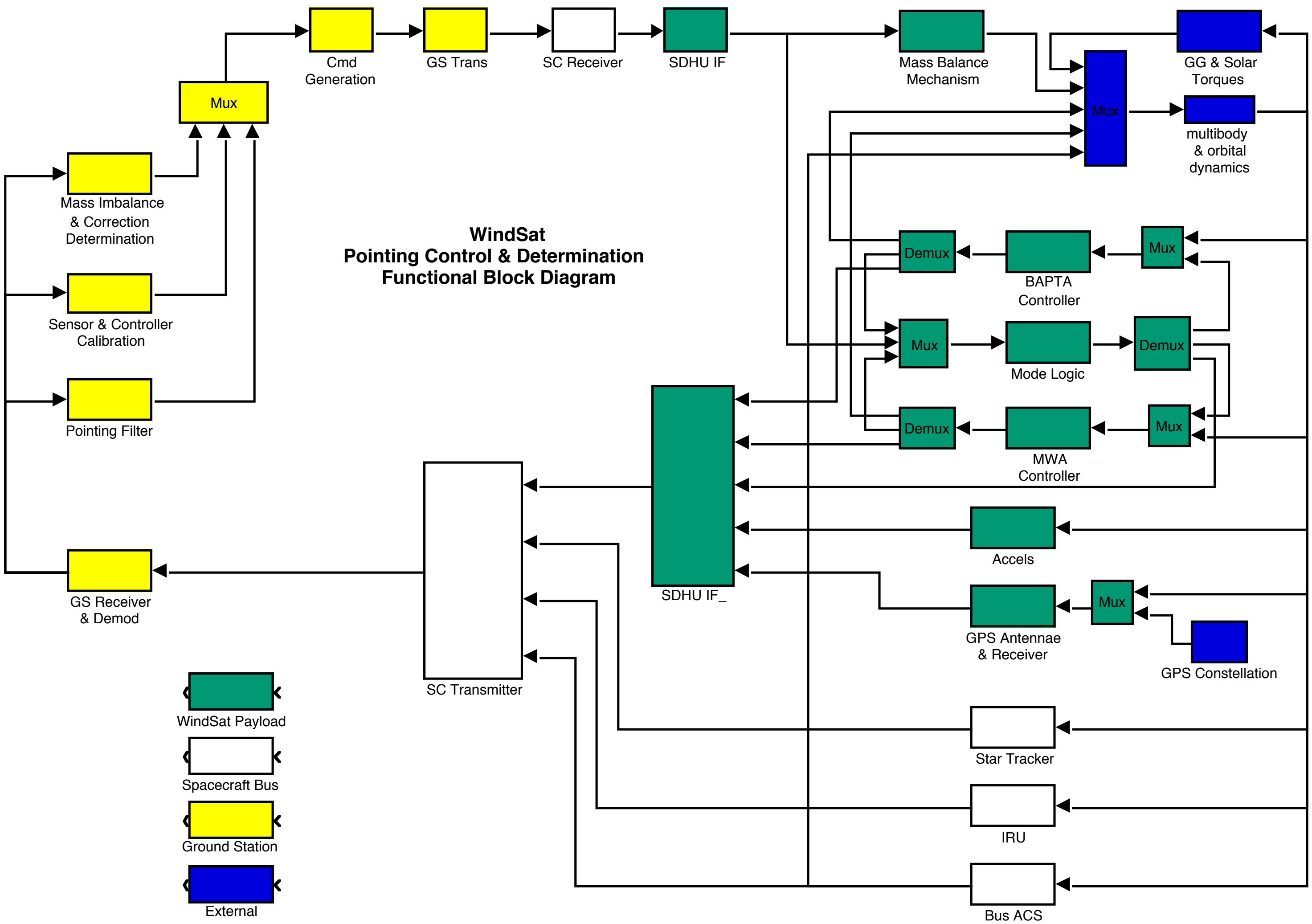
- The Only Factor Constraining Bus Yaw (Angle) Motion Is Rate Requirements and the Two Look Operation, i.e., If the Vehicle Yaws Then the Forward and Aft Scans Move off Center and the Overlap Will Be Reduced
- System Safe Hold Mode Will Require De-spinning the Payload
- SC Bus Will Normally Be Able to Give Advanced Warning of Required De-spin
- If Some Attitude Sensors (e.g., Star Trackers) Are Located on the PL; These Will Not Be Required for Initial Acquisition of the System
- Attitude Sensors Are Part of S/C Bus but Data Is Available via 1553 Bus
- PL Attitude Determination Code Is Ground Based

Top Level Goals, Assumptions and Derived Requirements (2 of 2)

Derived Requirements

- Maintain Residual Angular Momentum to < 1/3 of the Bus Capability
- PL Structural Modes Must Avoid All Payload/Bus Dist. Freq. (PL Spin, 1/2X PL Spin, MW Spin, Motor Cogging and Torque Ripple, Controller BW, Etc.)
- PL Structural Modes Must Avoid Bus Structural Modes (and Vice Versa)
- The PL Will Have the Capability to Trim Its Mass Properties to Meet the Imbalance Requirements
- Bus Must Provide for Initial Acquisition and Safe Hold Mode
- Bus Structural Modes Must Avoid All Payload/Bus Dist. Freq. (PL Spin, 1/2X PL Spin, MW Spin, Motor Cogging and Torque Ripple, Controller BW, Etc.)

System Functional Block Diagram



BAPTA/MWA Controller Design

BAPTA/MWA Controller Design

- Preliminary Controller Design Has Been Performed to Assess Whether the Associated Error Allocations, Spin Up, Sequence and Impact to the S/C Bus Are Reasonable

- MWA Controller Will Be Implemented As Part of SDHU

- BAPTA Controller Will Be Acquired As Part of BAPTA

  – NRL Design Provides Starting Point for Detailed BAPTA Controller Design

Top Level Controller Requirements

1 - Maintain Residual Angular Momentum to < 1/3 of the Bus Capability

2 - Provide for Spin Up, Spin Down, and Constant Speed Operation of the BAPTA and the MWA

3 - Provide Constant Scanning Motion (29.6 RPM)

4 - Provide Consistent Motion Relative to Cal Sources (Angle Repeatability < 0.15 deg.)

5 - Limit Contribution to Jitter Budget to < 1/10 Pixel (0.03 deg.)

6 - Provide Rate Control So That Contribution to Pixel Motion Error Is Less Than 1/10 Pixel Over 1 msec Integration Period (< .03 deg./msec)

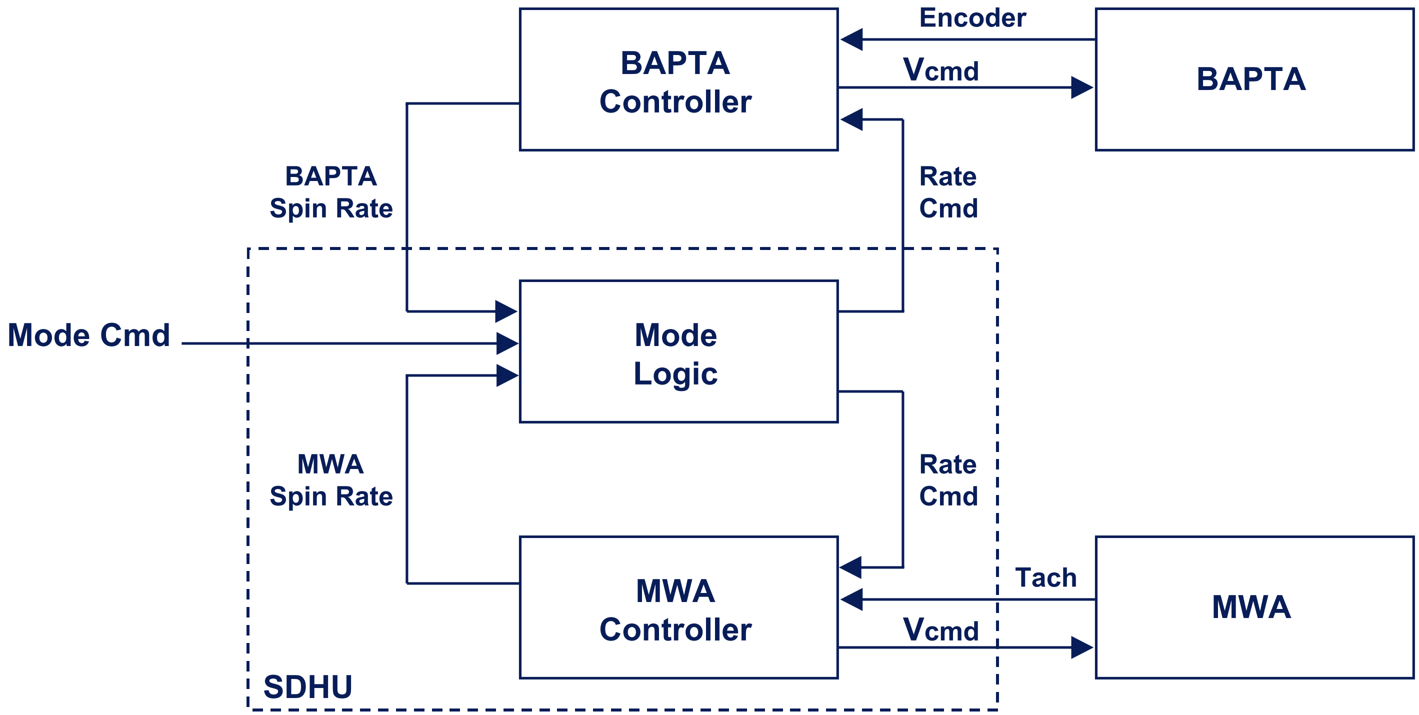
Controller Assumptions and Derived Requirements

- There Are Three Modes of Operation
  - Mode 1 (Operational): Independent Constant Speed Controllers
  - Mode 2 (Slaved): MWA Slaved to BAPTA
  - Mode 3 (Reverse Slaved): BAPTA Slaved to MWA (Failure Mode Only)
- The BAPTA and the MWA Controllers Must Be Designed Such That the Residual Angular Momentum and Torque Are Minimized
- Due to a Likely Significant Bandwidth Difference Between the BAPTA and MWA Controllers and Possible Controller Errors, the Spin-up and Spin-down Should Be Performed in Steps
- It Is Assumed That There Is No Bus Controller Interaction During BAPTA/MWA Controller Operation, i.e., Bus Controller Bandwidth Is Sufficiently Low

Derived Requirements - Angular Momentum Residual

Momentum Error Budget		Spin Axis		Trans Axis		Basis for Estimate
MW alignment to MW case		0	J-s	0.17	J-s	0.05 deg
MW case alignment to PL Structure		0	J-s	0.17	J-s	0.05 deg
MW Speed Control						
	Nominal	0.40	J-s	0	J-s	± .2%
	Peak	0.80	J-s	0	J-s	± .4%
PL spin alignment to PL structure		0	J-s	0.17	J-s	0.05 deg
PL Speed Control						
	Nominal	0.10	J-s	0	J-s	± .05%
	Peak	0.60	J-s	0	J-s	± .3%
RSS (nominal)		0.41	J-s	0.30	J-s	normal ops
RSS (peak)		1.00	J-s	0.30	J-s	spin up/down
Requirement (RSS nominal)		0.5	J-s	0.5	J-s	Based on RWA w/6 J-s capability
Requirement (RSS peak)		2	J-s	2	J-s	Based on RWA w/6 J-s capability

Functional Block Diagram



Estimated BAPTA Characteristics

BAPTA Characterists		
PL Izz	Kg-m^2	60
BAPTA Spin Rate	rpm	29.6
Viscous Drag Torque Coefficient	N-m/(rad/s)	0.045
Coulomb Friction Torque	N-m	0.224
No. of Motor Poles	nondim	12
Cogging Torque Amplitude	N-m	0.053
Motor Torque Ripple Coef.	nondim	0.03
Rate Meas. Frequency	Update/Rev	50
Rate Meas. Error (1 Sigma)	rpm	0.006

- **BAPTA Parameter Estimates Are Based on Existing BAPTA Designs**

- **Rate measurement Error Estimate Is Based on a 15 Bit Accuracy Encoder Sampled at the Measurement Frequency**

MWA Characteristics

MWA Characterists		
MWIzz	Kg-m^2	0.431
MW Spin Rate	rpm	4123
Viscous Drag Torque Coefficient	N-m/(rad/s)	6.7E-05
Coulomb Friction Torque	N-m	0.014
No. of Motor Poles	nondim	8
Cogging Torque Amplitude	N-m	0.007
Motor Torque Ripple Coef.	nondim	0.07
Rate Meas. Frequency	Update/Rev	1
Rate Meas. Error (1 Sigma)	rpm	16

- **MWA Parameters Are Taken From the MSX Reaction Wheel Specification and Test Data**

Controller Characteristics

BAPTA Controller Characteristics		
Bandwidth	rad/s	0.6
Phase Margin	Degrees	89
Gain margin	dB	inf

MWA Controller Characteristics		
Bandwidth	rad/s	0.9
Phase Margin	Degrees	89
Gain margin	dB	inf

- **Controllers Have Excellent Stability Margins and Provide Good Disturbance Attenuation at Disturbance Frequencies (1.5 and 3.0 Rad/Sec and Above)**

Controller Performance

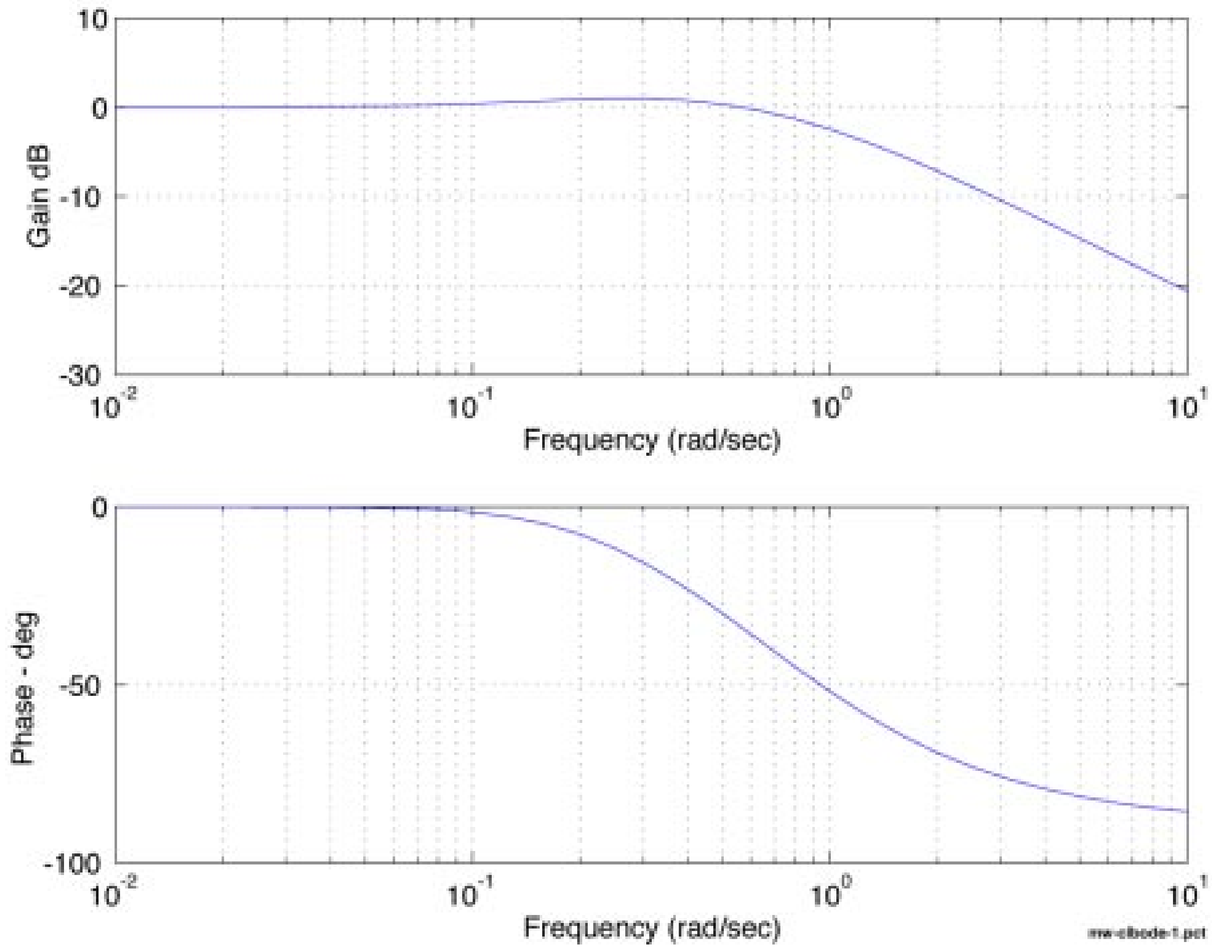
BAPTA/MWA 1 Sigma Angular Momentum Error (Mode 1)		
	Reqmnt	Perform.
MWA Ang. Mom. Error (N-m-s)	< 0.4	0.1
BAPTA Ang. Mom. Error (N-m-s)	< 0.1	0.02
Cal. Source Angle Repeatibility (Deg)	< 0.15	< 0.05

BAPTA/MWA Controller Performance (Mode 2)		
	Reqmnt	Perform.
Residual Ang. Momentum (N-m-s)	1.0	0.3
Resulting Bus Motion (Deg)	--	2.5*
Spin Up Duration (Minutes)	--	133

BAPTA/MWA Controller Jitter (Spin Axis Only)		
	Reqmnt	Perform.
Rate Stability (Deg/sec)	< 30	0.015
Angular Jitter (Deg)	< 0.03	0.01

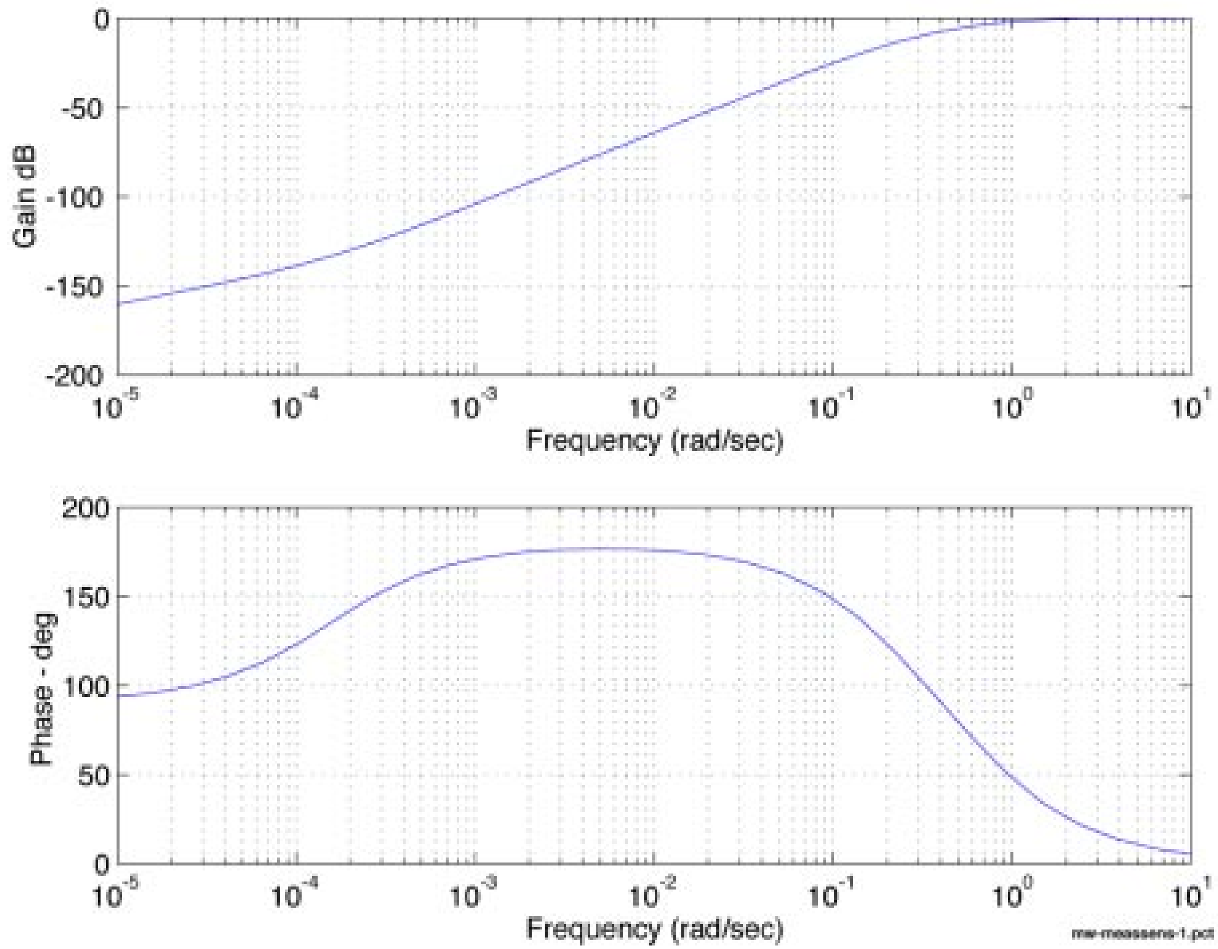
- **Bus Motion Is in Yaw and at Each Mode 2 Step. The Bus Izz Is Assumed to be 55 kg-m^2**

MWA Controller Design
Command Following – Wheel Only



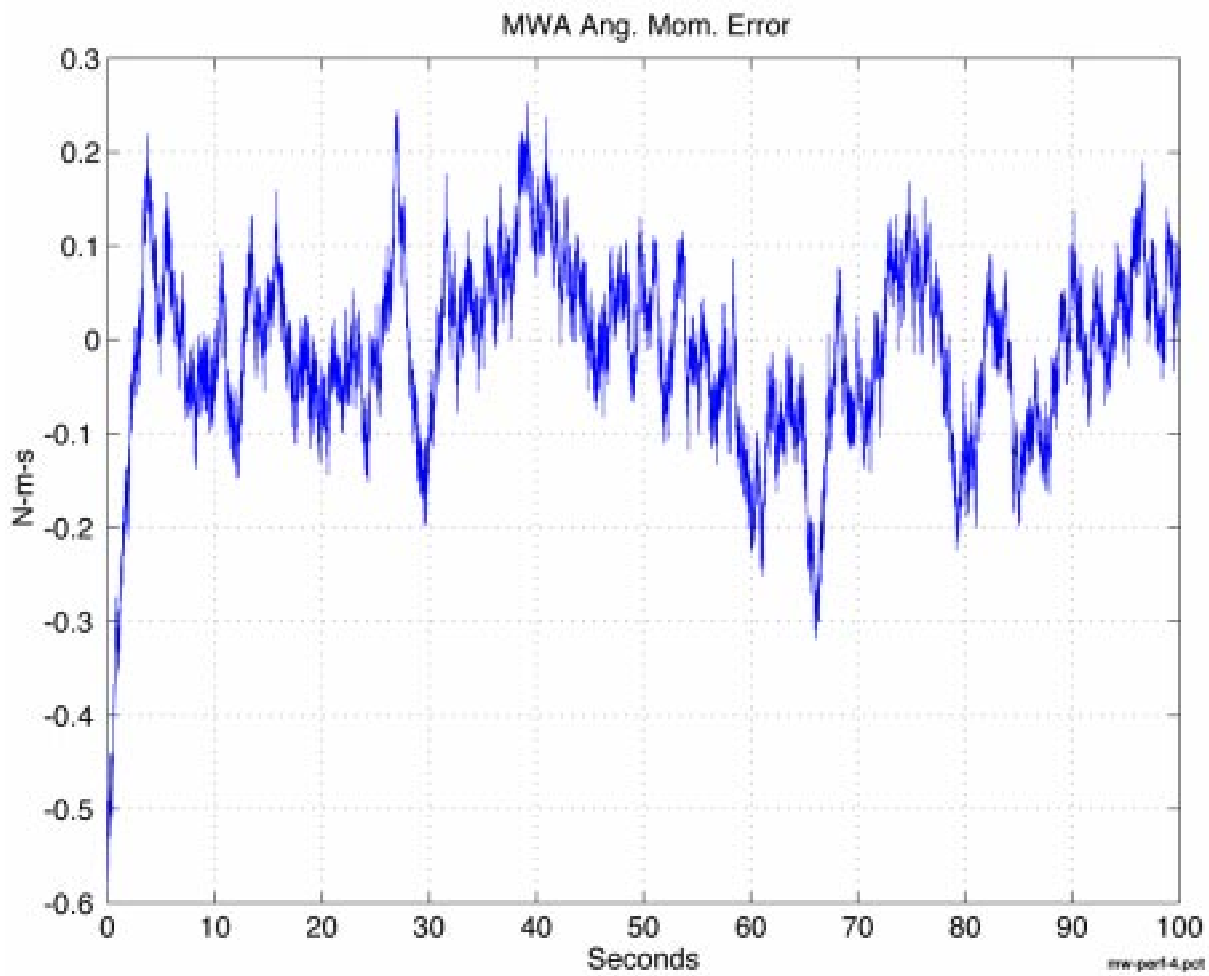
- **Good Low Frequency Rate Command Following Good Measured Error**
- **Good Attenuation Expected at Low Spin Rates**

MWA Controller Design
Base Motion Rejection - Wheel Only



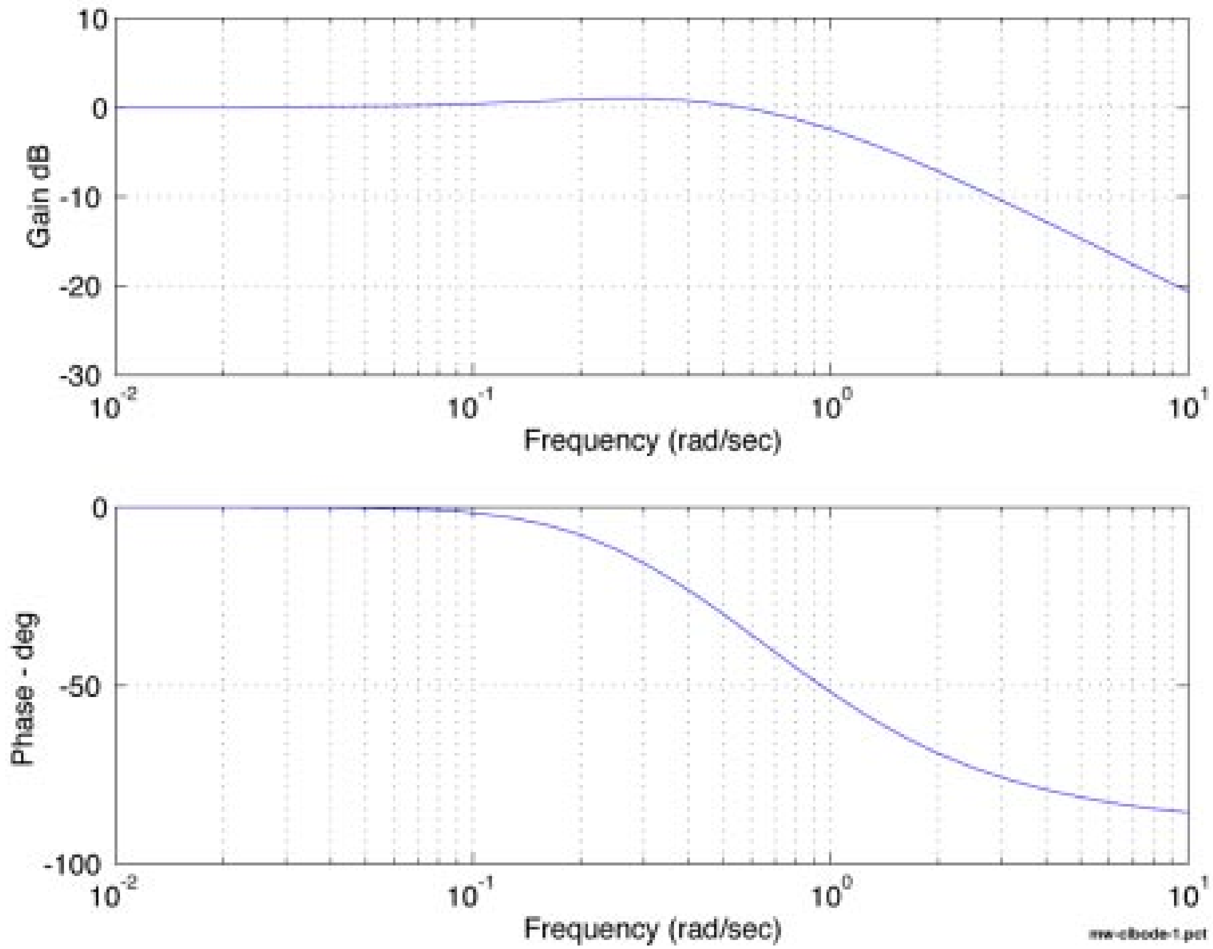
- **Shows Good Base Motion Rejection at Low Frequencies**
- **Poor Rejection at BAPTA Spin Frequency (Which Is What We Want)**

MWA Controller Performance
Mode 1



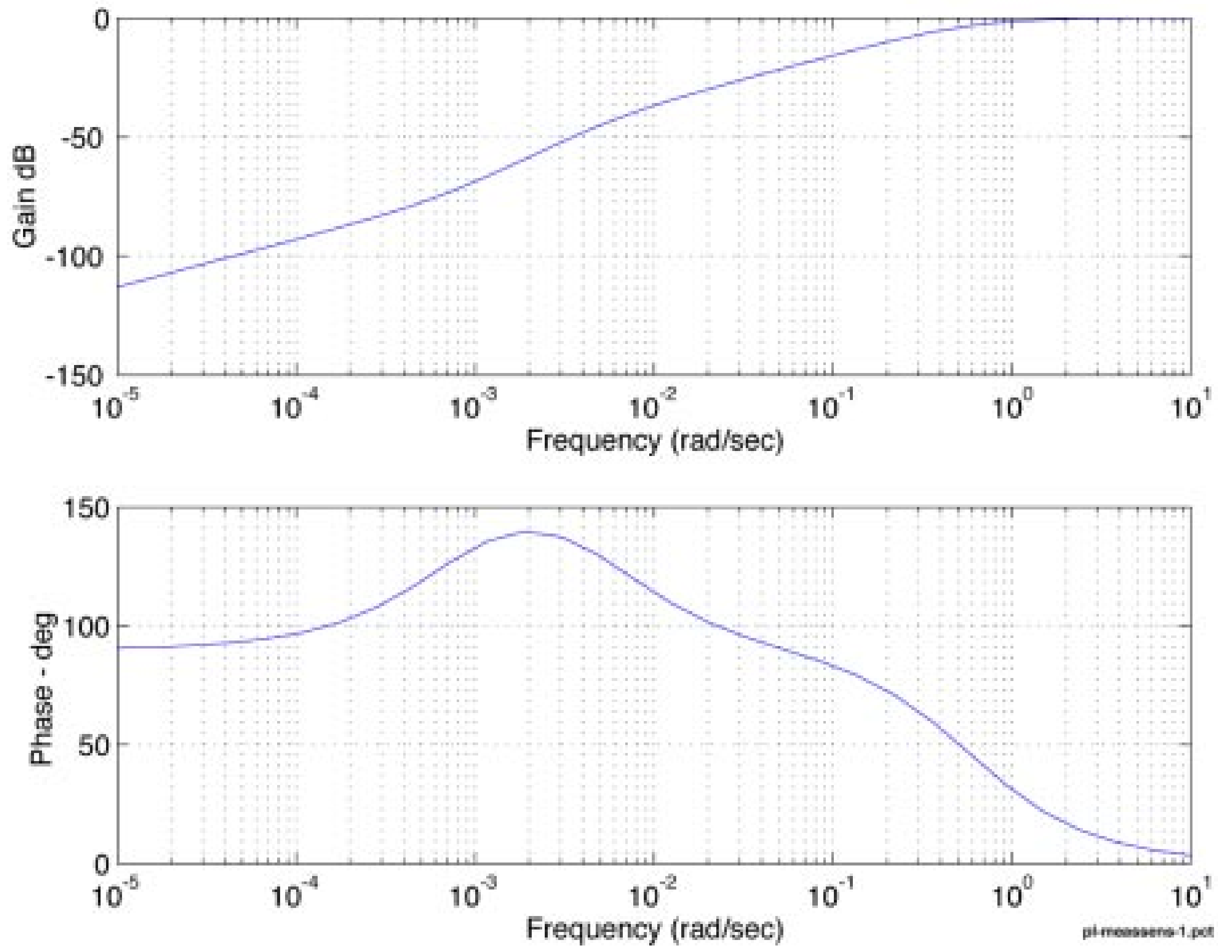
- **Steady State Performance Well Within 0.4 N-m-s 1 Sigma Requirement**

BAPTA Controller Design
Command Following - BAPTA Only



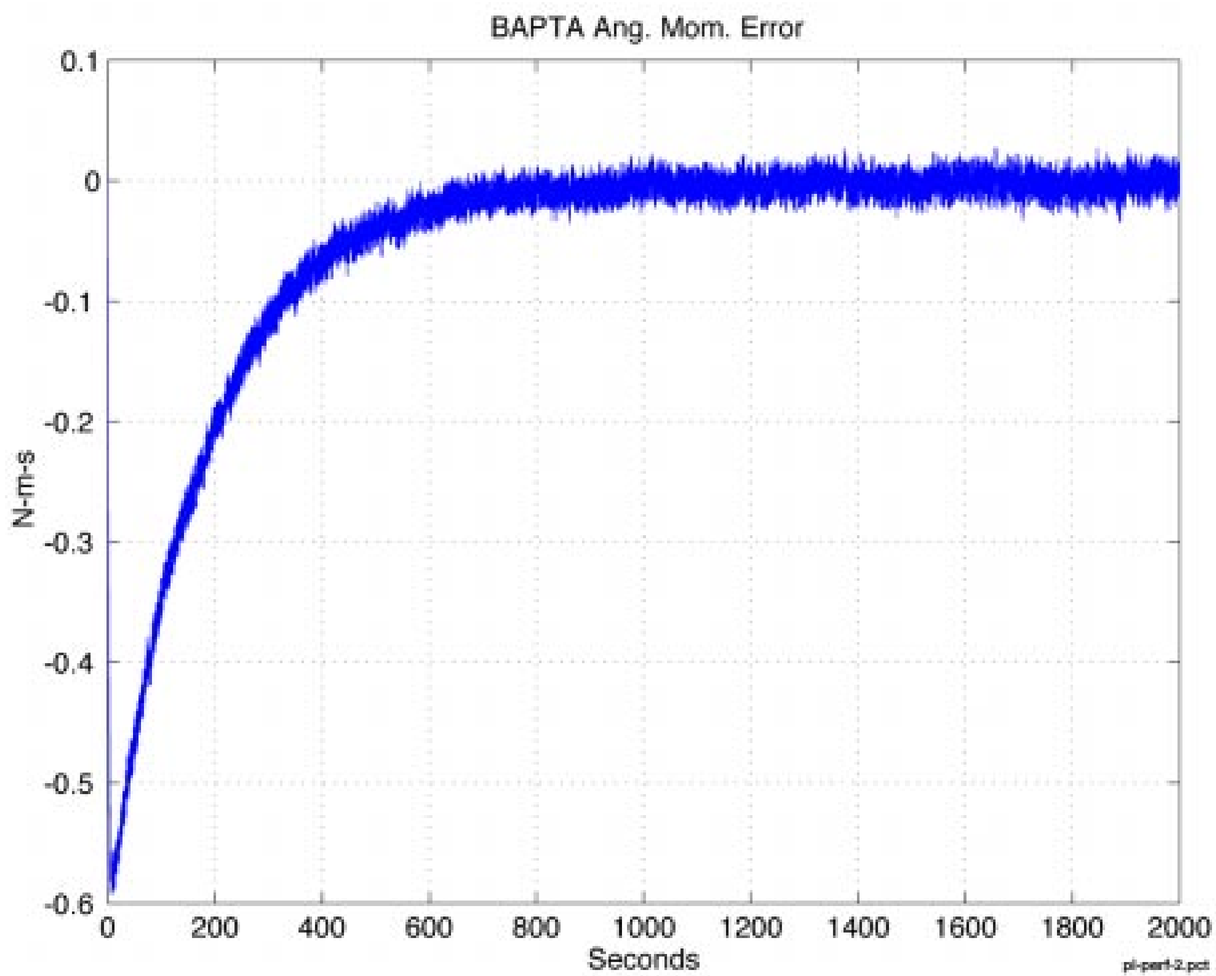
- **Provides Good Low Frequency Command Following Performance**
- **And Good Measurement Error Attenuation Expect at Low Spin Rates**

BAPTA Controller Design
Base Motion Rejection - BAPTA Only



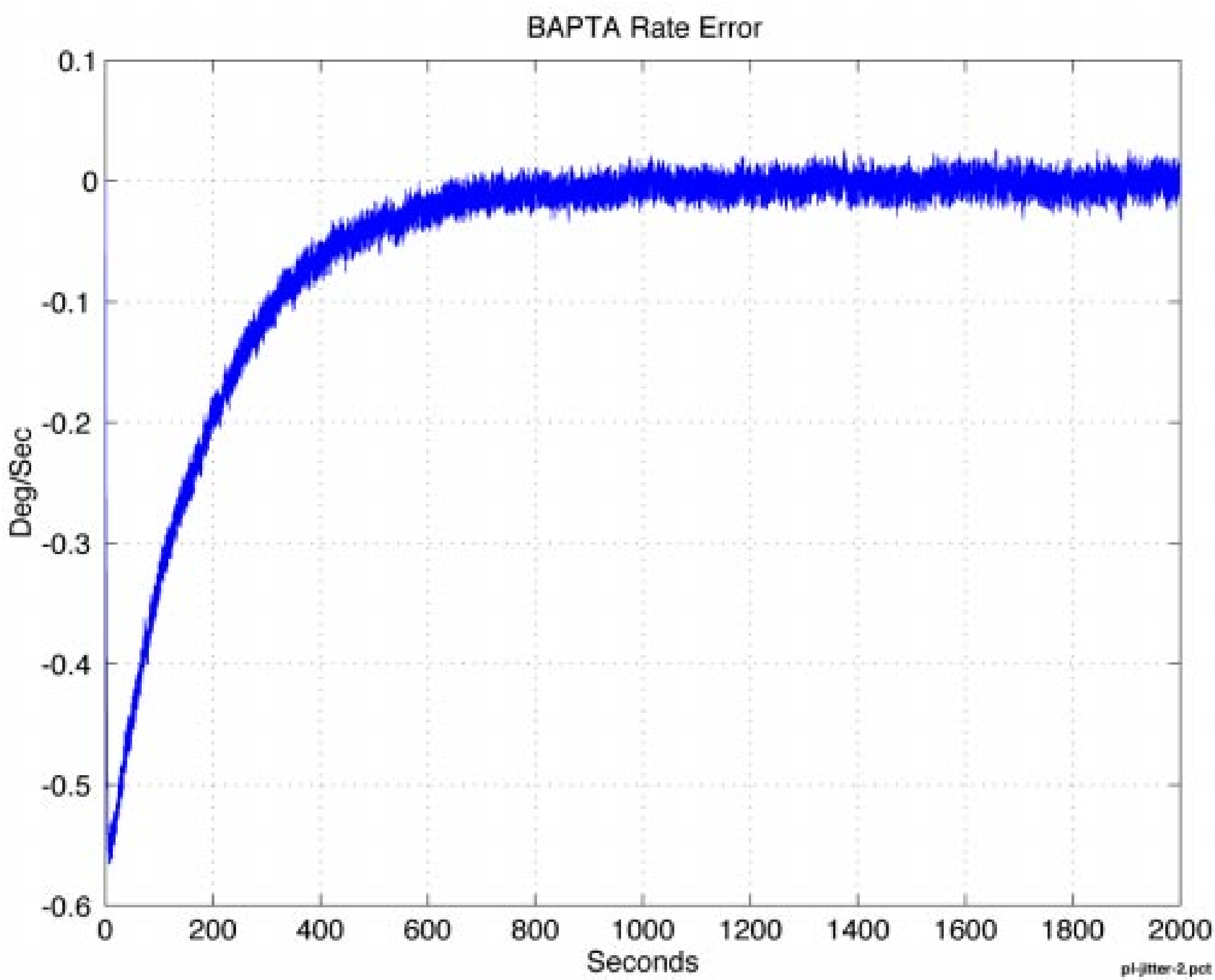
- **Shows Good Base Motion Rejection at Low Frequencies**
- **Poor Rejection at BAPTA Spin Frequency (As Desired)**

BAPTA Controller Performance
Mode 1

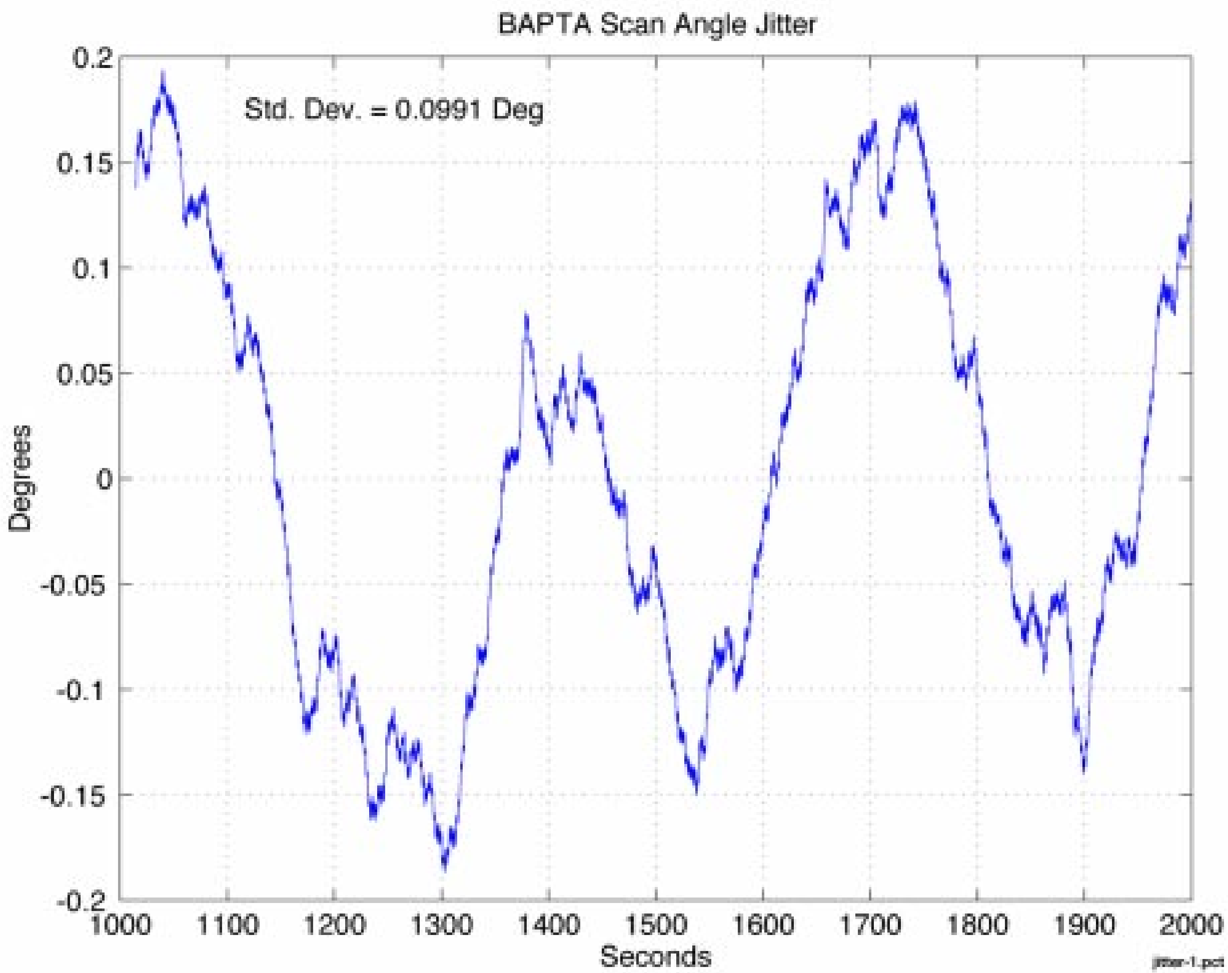


- **Steady State Performance Well Within 0.1 N-m-s 1 Sigma Requirement**

BAPTA Controller Performance Jitter (1 of 2)

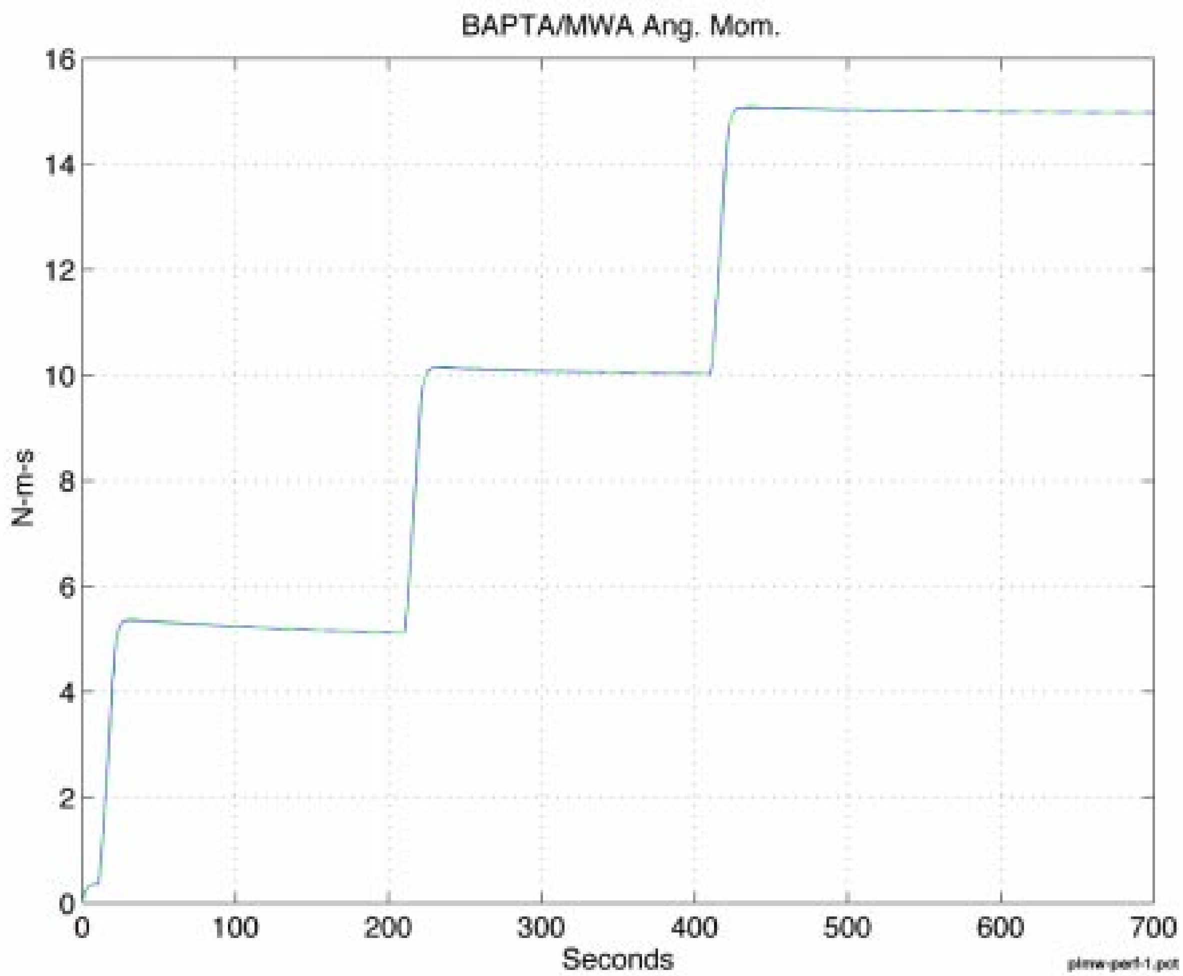


BAPTA Controller Performance Jitter (2 of 2)



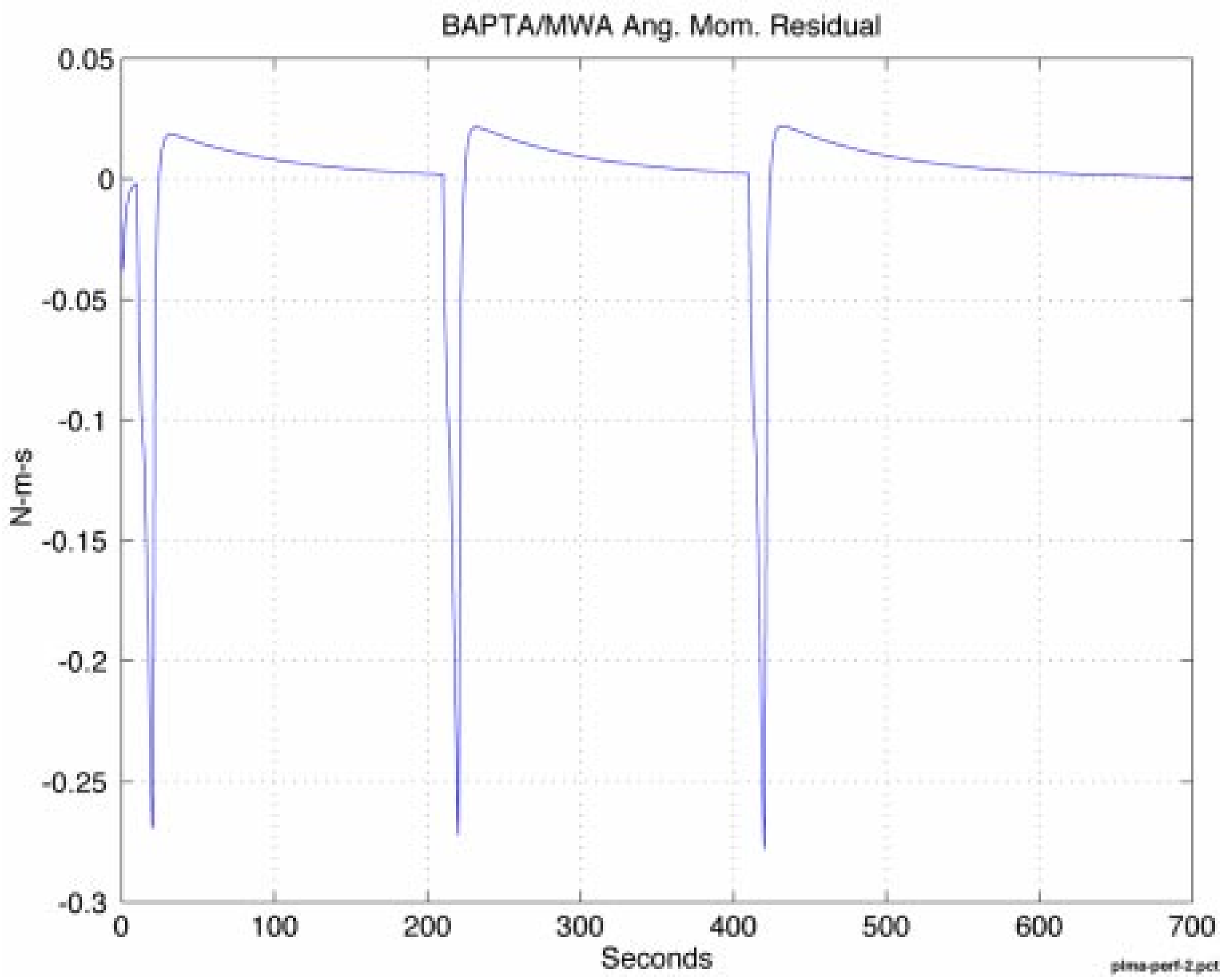
- **High Frequency Terms (Jitter) Are Well Within 0.03° Requirement**
- **Figure Also Shows BAPTA Scan Angle Repeatability Is Within 0.15° (Over 1/2 Spin Period)**

BAPTA/MWA Performance
Mode 2: 5 N-m-s Steps



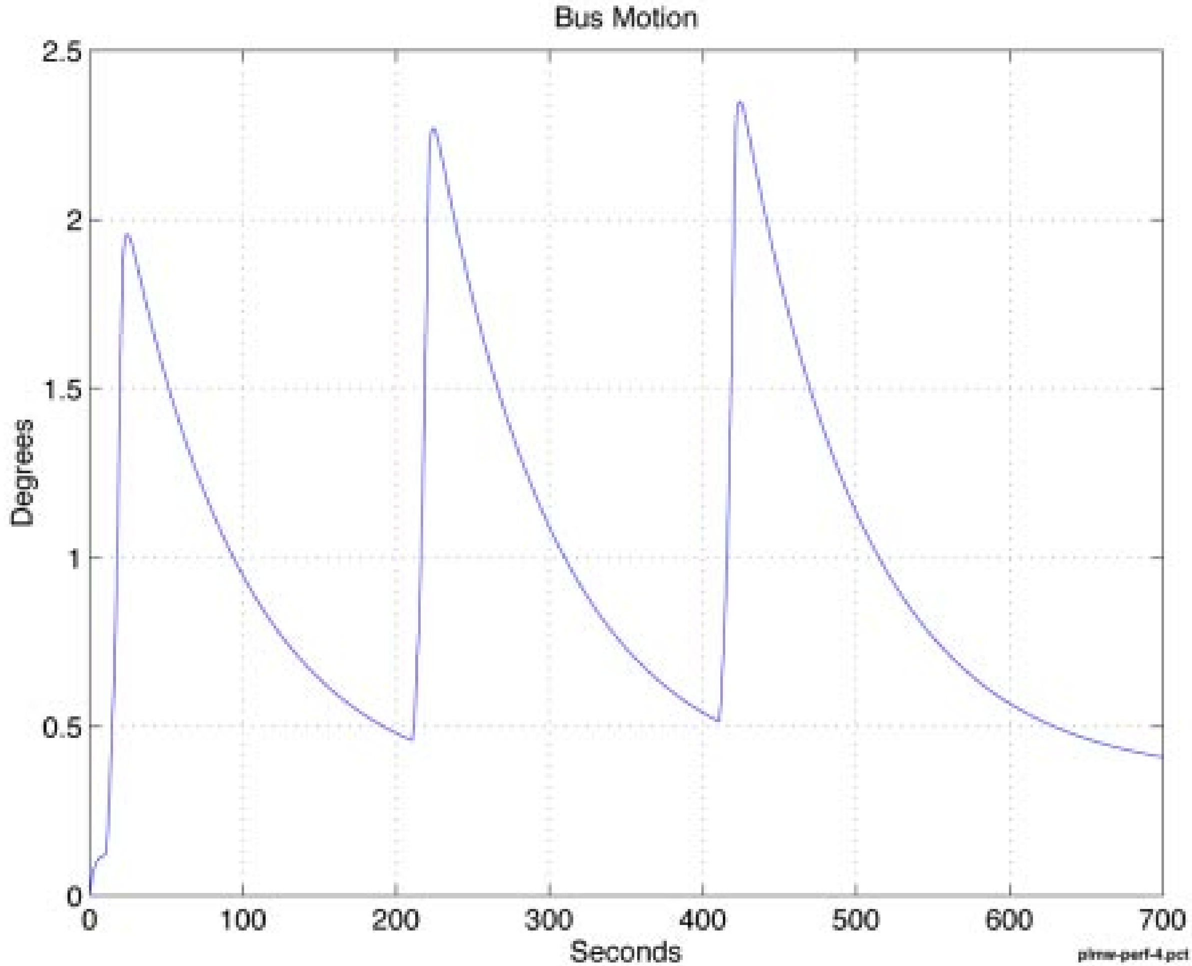
- **Shows 3 Spin Up Steps (Out of the 40 Required) and That Momentum Wheel Tracks the BAPTA**

BAPTA/MWA Performance
Mode 2: 5 N-m-s Steps



- **Angular Momentum Mismatch Peaks at Less Than 0.3 N-m-s**

BAPTA/MWA Performance
Mode 2: 5 N-m-s Step



- Izz Is Minimum Expected Give S/C Bus Options
- Shows Bus Yaw Motion for 3 Steps Assuming No Bus Control Response
- Low BW Bus Controller Will Limit Yaw Drift During Spin Up

BAPTA/MWA Controller Hardware Requirements

- MWA
  - Angular Momentum Storage > 195 N-m-s
  - Motor Torque > 0.24 N-m
  - Spin Axis Alignment Error < 0.05°
  - Tach Signal Leading Edge Jitter < 1.4° (52 μSec @ 4500 rpm)
- BAPTA
  - PL Angular Momentum < 195 N-m-s @29.6 rpm + 5%
    - Implies Spin Inertia < 60 kg-m^2
  - Net Motor Torque > 0.15 N-m
  - Spin Axis Alignment Error < 0.05°
  - Encoder Position Error < 0.011°

Mass Balance Mechanisms

- **Preliminary Simulations Indicate Ground Spin Balance May Yield Acceptable Static and Dynamic Mass Balance**

- **Capability of NRL Spin Balance Table (40 oz in) Will Result in Less Than ± 0.03 Degrees Attitude Motion (S/C Dependent)**

- **Mass Balance Mechanisms Will Still Be Required Pending Spin Balance Test and Selection of a S/C Bus**

Payload Imbalance and Line-of-Sight (LOS) Estimation

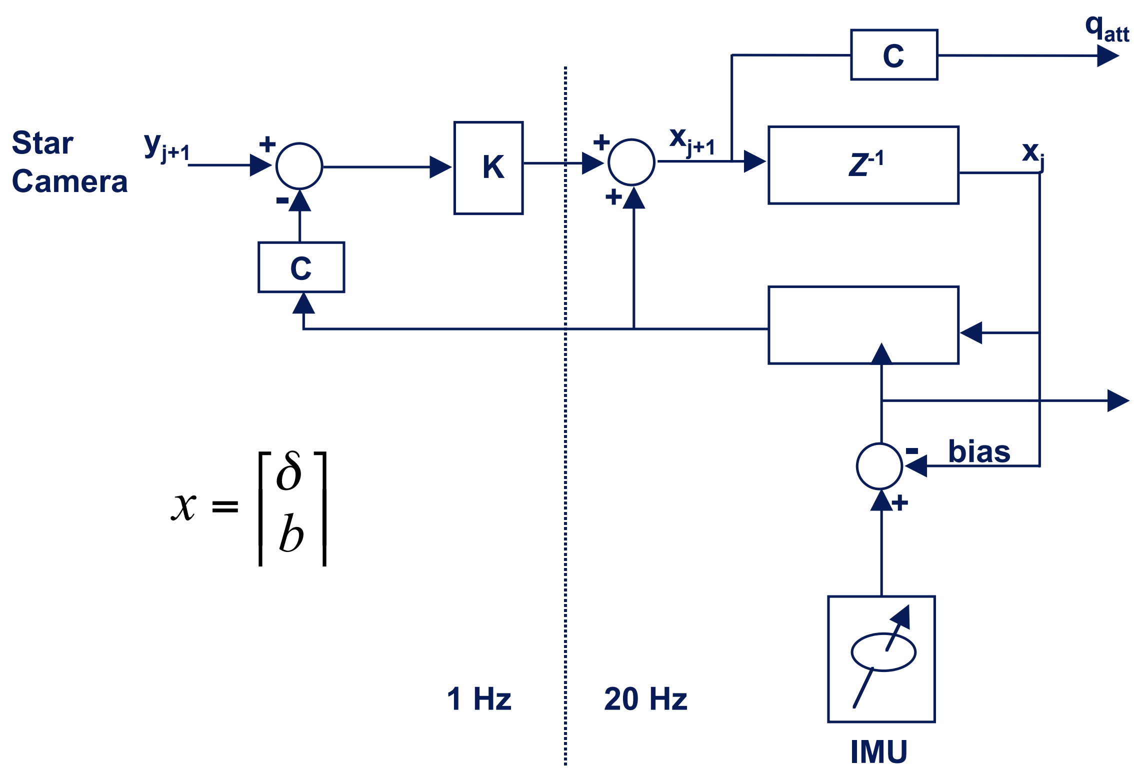
Attitude, Payload Imbalance, and Line-of-Sight (LOS) Estimation

- Top Level Requirements (1 Sigma):
  - EIA, PRA Knowledge Error < 0.05°
  - Geolocation Error < 0.06°
  - Provide Mass Imbalance Determination Required For Trimming The Mass Properties
- Baseline Assumptions:
  - Ground Data Processing (All Required Data Available at POC)

Payload Imbalance and LOS Estimation

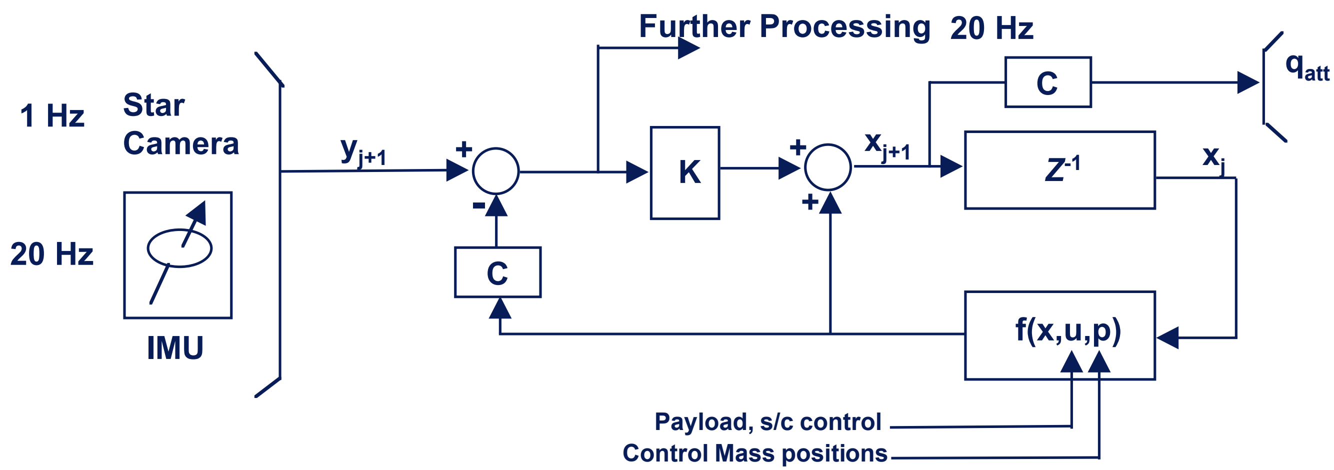
- Attitude Determination Achieved Using Either :
  - A Classic Six-State "Model-replacement" Kalman Filter, or
  - A Conventional Nine-State Extended Kalman Filter With "Tap" on Residuals for Post-Processing
- Payload Imbalance Estimation Achieved by One of Two Methods; Both Approaches Rely on Dynamic Model of Unbalanced Spinning Mass
  - Post-Processing Kalman Filter Residual
  - Use Separate Parameter Estimation Algorithm
- LOS Estimation (SAA, EIA, PRA) Is "Open-Loop" Process Dependent Upon the Attitude Determination System, Orbit Determination System, Payload Scan Angle Measurement System, and System Timing Uncertainties

Classic Six-State "Model Replacement" Kalman Filter



$$x = \begin{bmatrix} \delta \\ b \end{bmatrix}$$

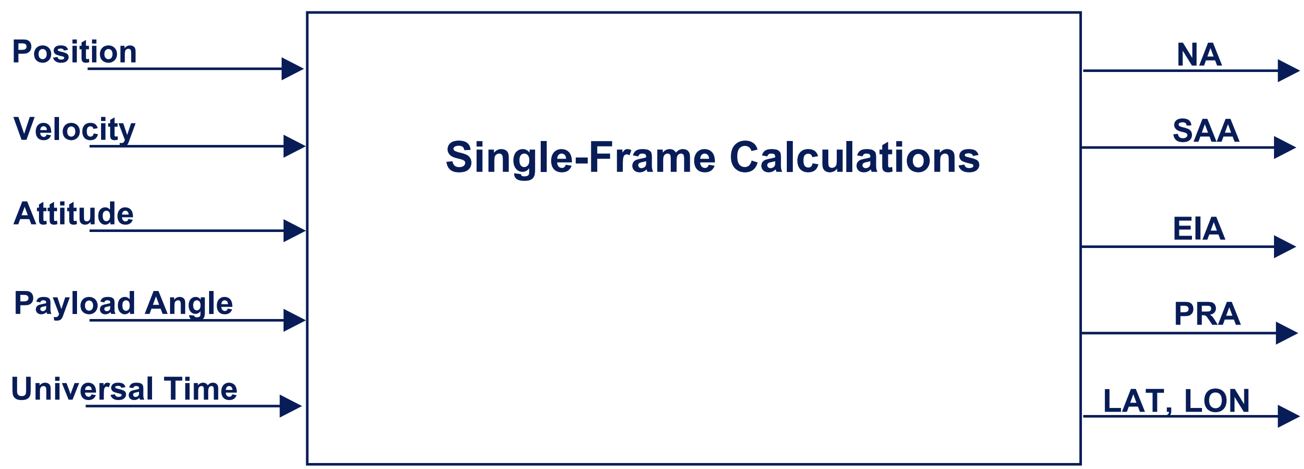
Conventional Nine State Attitude Kalman Filter



$$x = \begin{bmatrix} \delta \\ \omega \\ b \end{bmatrix}$$

NA, EIA, SAA, PRA Estimation and Geolocation

- Nadir Angle (NA) Is Function of PL LOS, Spacecraft Attitude and Payload Rotation
- EIA Is Function of NA, Spacecraft Position (for Geodetic EIA), and Payload Rotation
- SAA Is Function of PL LOS, Spacecraft Attitude and Payload Rotation
- PRA Is Function of Spacecraft Attitude, Payload Rotation, and Location of Phase Angle Reference (in Payload Frame)
- Geolocation Is a Function of NA, SAA, Spacecraft Position, and UTC



NA, EIA, SAA, PRA Estimation and Geoloc. Performance Allocations

	Bias	System	Random
• BAPTA Scan Angle	0.007°	0.000°	0.011°
• Attitude Determination	0.010°	0.000°	0.015°
• Orbit Determination			
– Position	200 m	0.0 m	200 m
– Velocity	10 cm/s	0.0 m	10 cm/s
• Geoid Modeling	0.000°	0.000°	0.000°

- Performance Allocations Are Extracted From the Error Budget and Are 1 Sigma Values
- The BAPTA Scan Angle Allocation Requires an Encoder of At Least 15 Bit Accuracy
- The Position Determination Is Well Within the Capability of Single-Frame GPS Calculations (Even With Selective Availability Corruption)
- The Rate Determination Will Require Data Filtering (Demonstrated Using TOPEX GPS Data)
- Geoid Modeling Assumes Near Perfect Correction for Earth Oblateness and Higher Order Terms

Attitude Estimation Performance Allocations

- Attitude Determination Requirements Are Typical of Star Tracker/IRU Combination
- Covariance Analyses Give Indication of Sensor Performance Requirements
  - 4 Sensor Combinations Using Single Star Tracker and IRU
  - A Star Tracker Boresight Is Along the Pitch Axis
  - Update Rates Depend Upon Sensors Used

	Random Walk (deg/rt hr)	Bias Stability (deg/hr)
IRU 1	0.03	0.2
IRU 2	0.15	2

	Cross-boresight Error (arcsec, 1 sigma)	Boresight Roll Error (arcsec, 1 sigma)
ST 1	2.3	23.8
ST 2	100	300

Attitude Estimation Covariance Analysis

Axis	IRU1/ST2	IRU1/ST1	IRU2/ST2	IRU2/ST1
Roll	9.50E-03	6.50E-04	2.20E-02	9.50E-03
Pitch	1.80E-02	2.00E-03	4.10E-02	1.90E-02
Yaw	9.50E-03	6.50E-04	2.20E-02	9.50E-03

Std Deviation Of Attitude Estimation Error (Deg)

Axis	IRU1/ST2	IRU1/ST1	IRU2/ST2	IRU2/ST1
Roll	1.40E-02	7.50E-03	7.50E-02	6.50E-02
Pitch	2.20E-02	8.00E-03	9.10E-02	7.20E-02
Yaw	1.40E-02	7.50E-03	7.50E-02	6.50E-02

Std Deviation Of Attitude Estimation Error (Deg) After 100 Seconds Of IMU Propagation Without ST Updates

- **Only IRU 1/ST 1 Combination Meets Attitude Determination Requirement After 100 Sec Star Tracker Data Drop Out**
- **Best Combination If Only 1 Star Tracker Is Used**

Mass Imbalance Estimation
Sensor Requirements

- **Sensor Requirements Are Derived By Studying the Multibody Equations of Motion and by Simulation of the Vehicle Motion**
- **Sensors Required Include IRU and Three Accelerometers**
- **IRU Must Have a Measurement Range of ±2 deg/sec and a Resolution of 0.0002 deg/sec**
- **The Accels Must Have Measurement Range of ±0.01 G and a Resolution of 1 μG (Depending on Location).**
- **To Achieve Desired Signal to Noise Ratio, the Noise Should be Below 10 μG**
- **Alignment of Each Axis Is Crucial for Axes With Relatively Small Signal**

Accelerometer Requirements	
Input Range	±0.01 g
Frequency Response	
0 - 10 Hz	0.01 dB
0 - 20 Hz	0.40 dB
Resolution	1 μg
Noise (0 - 10 Hz)	10 μg
Axis Misalignment	0.1 deg

Attitude, Payload Imbalance, and Line-of-Sight (LOS) Estimation

- Derived Requirements:
  - Ground Software Required for Attitude and Orbit Estimation, LOS Estimation, Geolocation, and PL Imbalance Estimation (May Be Combined Filter)
  - Raw, Time Tagged Sensor Data Available at POC
  - Data Sample Frequency Requirements
    - IRU Data at > 20 Hz
    - ST Data at > 1 Hz
    - Encoder Data at > 50 Hz
  - Time Tagging Requirements
    - ST, IRU, GPS < 1 msec
    - BAPTA Encoder < 10 μsec

Momentum Wheel Assembly

Momentum Wheel Assembly (MWA)

MWA Specs

Parameter	Unit	Enhanced HR150
Angular Momentum	N-m-s Ft-lb-s	203 150.0
Output Torque	N-m oz-in.	1.62 230.0
Peak Power	W	1100
Power While Holding Maximum Speed	W	50.0
Wheel Speed	RPM	4500
Weight	Kg Lb	27.7 61.0
Outside Diameter	Mm In.	457 18
Height	Mm In.	228.6 9.0
Operational Temperature Range	°C-Low °C-High	-20 +60
Interface	Analog/ Digital	Analog

MWA

- The MSX Wheel Was Chosen Because It Met the MWA Requirements and Was Available As GFE, However, Several Issues Have Come to Light
  - Inertia Growth
  - Potential Issues and Design Modifications
    - Bus Voltage Required to Compensate Back EMF
    - Wheel Speed Limiter
    - Desire to Limit Torque Cmd/Power Consumption
  - Lack of Full Acceptance Testing
- The EDU Will Be Tested in Early FY99
- Performance Analyses and Design Mods Will Be Completed in Early FY99

Integration and Testing

- **Major Tests Include:**
  - **Mockup Spin Balance**
  - **MWA EDU/PC CTRL Testing**
  - **MWA Acceptance Testing**
  - **MWA EDU/DHU EBB Closed Loop Testing**
  - **MWA EDU/BAPTA SIM/DHU EBB Closed Loop Testing**
  - **Mass Balance Testing on Mockup (Simulated Sensor Data)**
  - **MWA/DHU Closed Loop Testing**
  - **Protoflight Spin Balance**
  - **BAPTA/MWA/SDHU Closed Loop Testing**
  - **BAPTA/MWA Spin Axis Alignment**

Integration and Testing Equipment

- **Test Equipment Required:**
  - Spin Balance Machine
  - Interface to SBM for Data Recording
  - PC and Interface Board
  - Power Supply
  - BAPTA Simulator (EDU Preferred; Need Rate Encoder Output, Rate Output, Torque, etc.)
  - SDHU EBB

Mechanical Aerospace Ground Equipment (MAGE)

Pogue

WindSat MAGE Categories

- Development/ I&T
- Handling / Lifting
- Alignment / Calibration
- Shipping / Storage / Protection

Development / I&T Requirements

- WindSat Structure Mockup With Integral Lift Points
  - Handling / MAGE Development
  - Wiring Harness Fabrication
- Rotary Table
  - Assembly Ease
  - Line of Sight Determination for Alignment Development
- WindSat Test Fixture
  - Reconfigurable to Accommodate Interface Change
  - Structure Mock-up, Handling, Ballast
  - Test Interface: Shock / Vibe / Acoustic, Spin Balance, Thermal / Vacuum

Handling / Lifting Requirements

- WindSat Structure Lifting Fixtures
  - Lift WindSat in a Variety of Configurations
    - Mockup
    - Truss Only
    - Canister Only
    - With / Without Reflector
    - With / Without Feedbench
    - With / Without Spacecraft
  - Reconfigurable
    - Adjustable For CG
    - Number / Location of Lifting Points
- WindSat Feedbench Fixture
  - Lifting / Handling
  - Assembly

Alignment/Calibration Requirements

- Antenna Alignment
  - WindSat Handling Fixture
  - Alignment, Rotation
- WindSat RF Range Test Adapter
  - Multi-axis Capable Fixture
  - WindSat to RF Range Apparatus
  - Rotation About Spin Axis
  - Repeatable Reinstallation
  - Withstand Outdoor Use

Shipping/Storage/Protection Requirements

- WindSat Shipping Containers
  - To and From RF Range Tests, Delivery to Launch Vehicle
  - Shock Recorder Equipped
  - Configurations Required
    - Fully Assembled Payload
    - Truss Only
    - Canister Only
    - Feed Bench Only
- Reflector Cover/Lifting Fixture
  - Protect VDA Surface
  - Remove / Replace with Reflector Installed on / off Truss

MAGE Implementation

- **Design Definition Complete**
- **Detailed Design in Progress**
- **Build / Buy As Needed As WindSat Components Are Completed**
- **Buy With Components As Appropriate**
  - **Main Reflector**
  - **Cold Reflector**

System Calibration/Validation

K. St.Germain

Cal/Val Requirements

- Calibrate: Characterize Instrument Performance
  - Brightness Temperature Measurement Accuracy
  - Geolocation Accuracy
  - Includes Ground Data Reduction Process
- Validate: Wind Measurement Capability
  - WindSat Based Wind Vector vs. Ground Truth

Polarimetric Radiometry

- Ocean Surface Emission Varies With Wind Speed and <u>Direction</u>
- SSM/I <u>Wind Speed</u> Retrievals Are Being Used Operationally With Accuracy Better Than ±2 m/s
- Aircraft Measurements Have Shown That the <u>Wind Direction</u> Signal Is Measurable From 10–37 GHz at Broad Range of Wind Speeds
- Wind Direction Dependence Arises From Anisotropic Distribution and Orientation of Wind Driven Waves
- Polarimetric Radiometry Measures the Stokes Vector Which Describes the Polarization Properties of the Emitted Radiation
- Stokes Vector Contains Information Needed to Measure the Ocean Wind Vector

$$
I_s = \begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix} = \begin{bmatrix} T_v \\ T_h \\ T_{45} - T_{-45} \\ T_{lc} - T_{rc} \end{bmatrix} = \begin{bmatrix} \langle E_v E_v^* \rangle \\ \langle E_h E_h^* \rangle \\ 2\,\mathrm{Re}\langle E_v E_h^* \rangle \\ 2\,\mathrm{Im}\langle E_v E_h^* \rangle \end{bmatrix}
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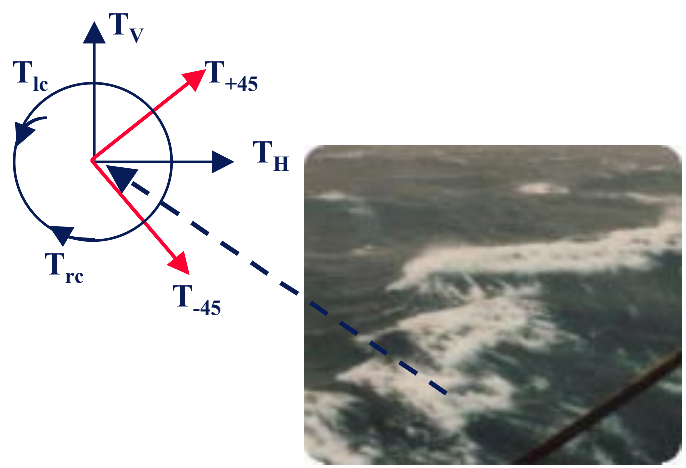
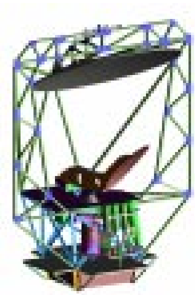


Smwave.jpg

Cal/Val Products



grnd_station.eps

Calibration

- Absolute Accuracy
- Polarization Purity
- Geolocation Accuracy
- Essential Archival Products

Validation

- Wind Vector
- Sea Surface Temperature (SST)
- Water Vapor
- Cloud Water
- Rain Flag

Satisfies

Mission Success

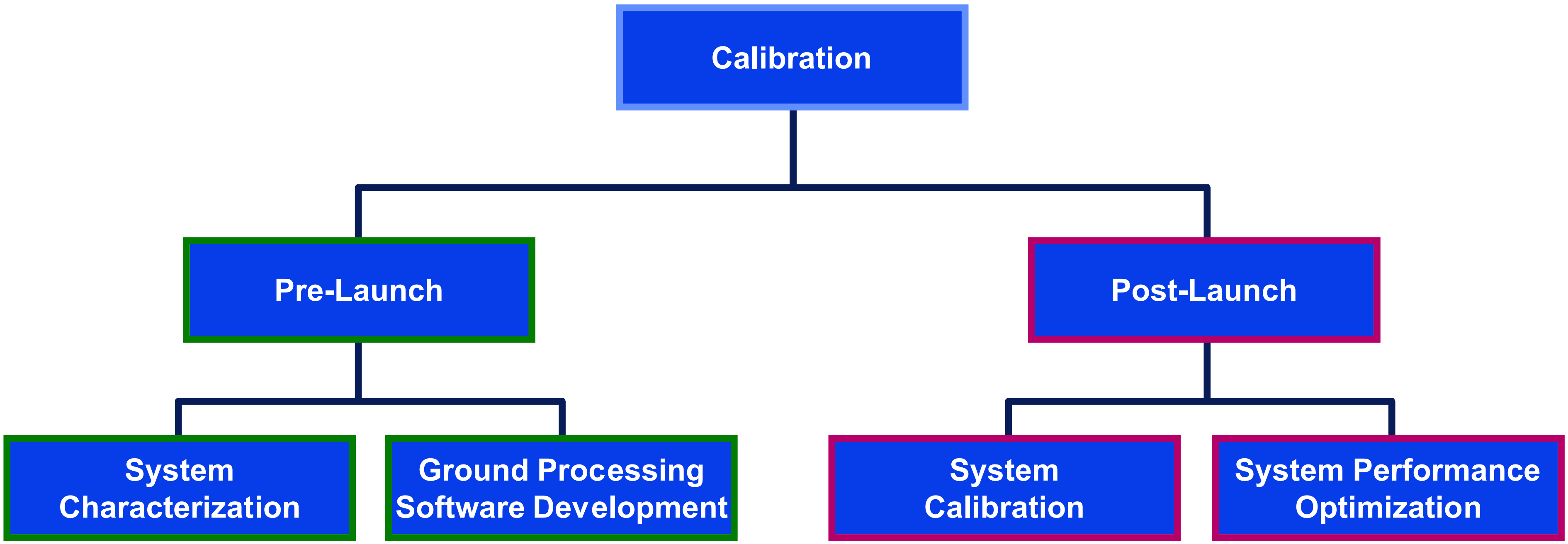
- Passive Microwave Polarimetric Sensing of Global Ocean Wind Vector
- Risk Reduction for NPOESS
- Quasi-Operational Products

Real Time

User

Archive

Calibration

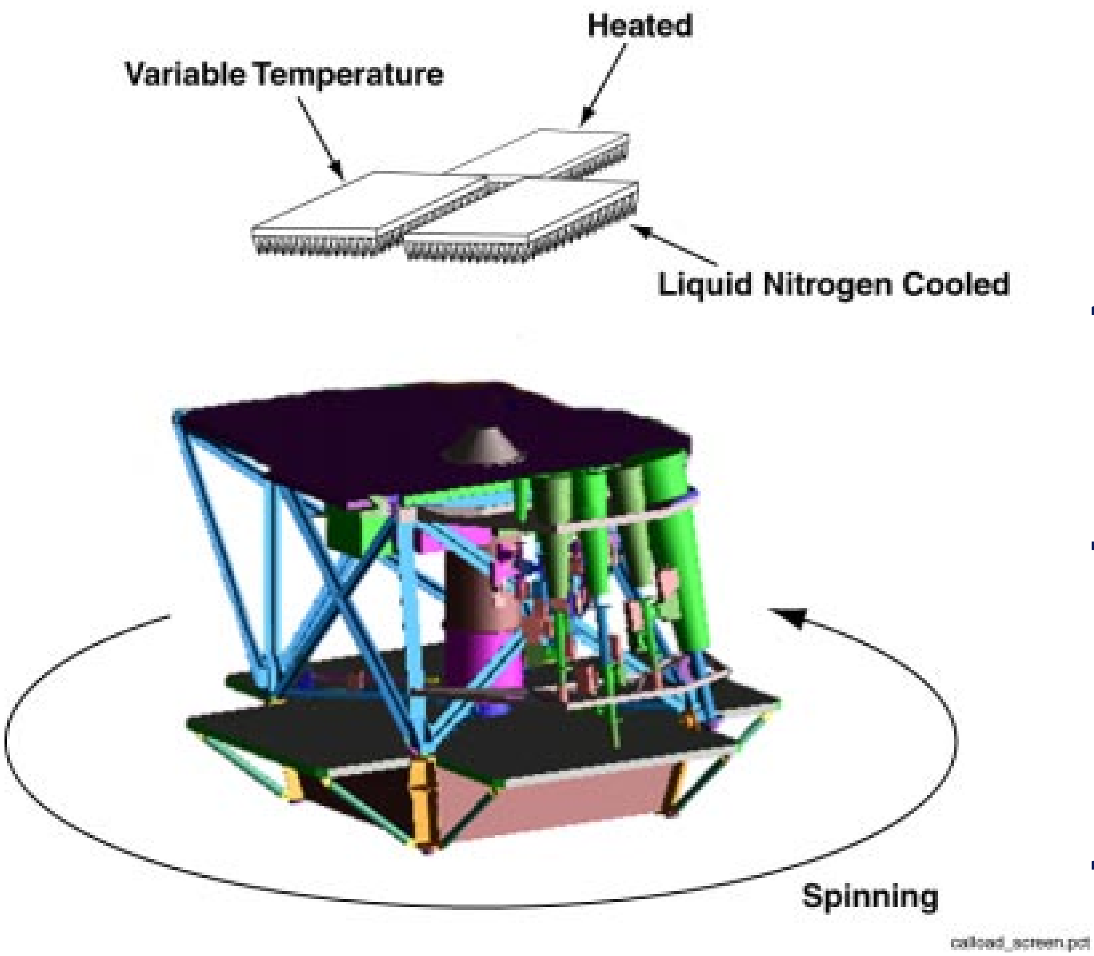


Pre-Launch Calibration

- Pre-Launch
  - System Characterization
    - Subsystem Level*
      - Receivers
        - Noise
        - Gain Stability
      - Warm Calibration Target
        - Emissivity
        - Polarization Purity
        - Stability
      - Main Antenna Characterization
        - Beam Efficiency
        - Polarization Purity
        - Feedhorn Spillover
        - Beam Uniformity/Sidelobes
        - Beam Boresight (Az, El)
      - Cold Space Reflector Characterization
        - Beam Efficiency
        - Sidelobes
      - Mechanical Alignment
        - Boresight
        - Stability
    - System Level
      - System Dynamic Range
      - Absolute Calibration Accuracy
      - Channel Sensitivity NEDT
      - Warm Load Correction
      - System Linearity
  - Ground Processing Software Development
    - Raw Data Record
    - Temperature Data Record
    - Sensor Data Record

*Levied on Subsystems

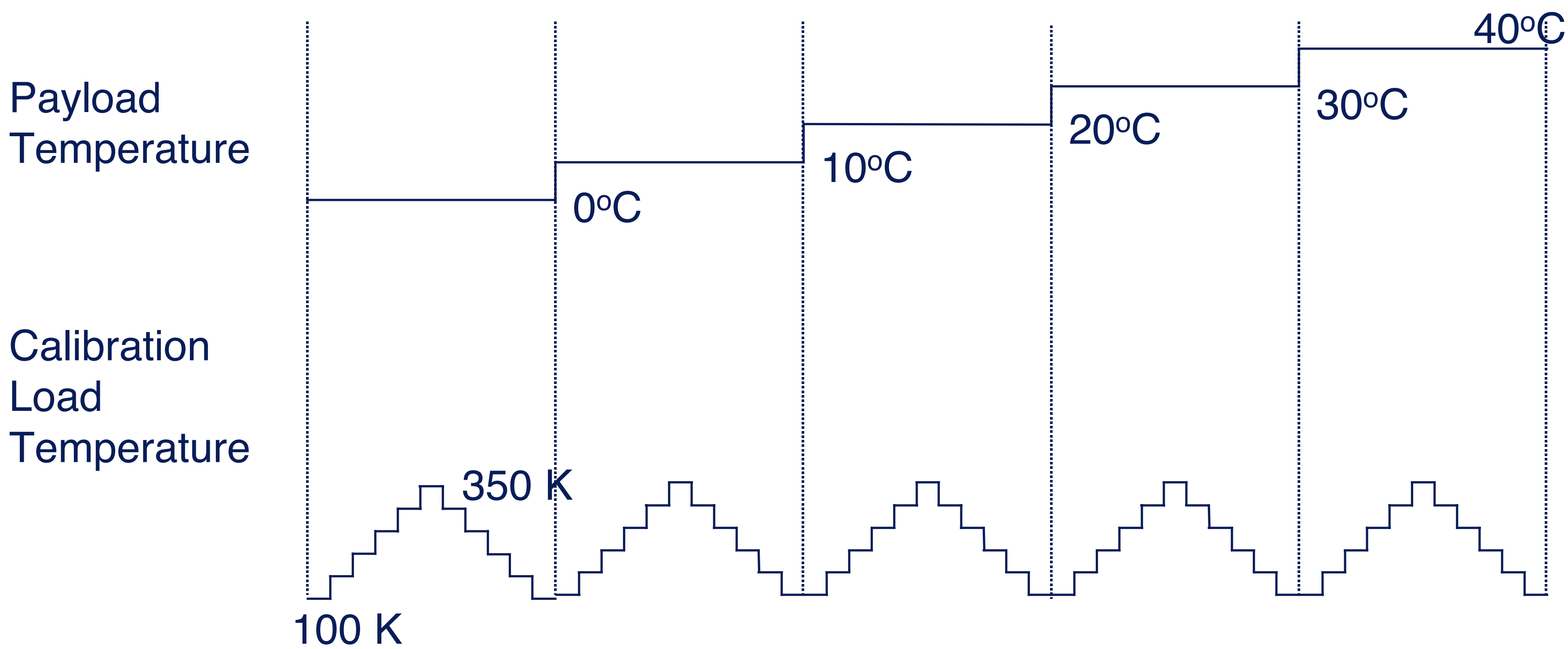
System Calibration in Thermal Vac



Test Targets

Flight Payload

Radiometer Calibration in Thermal/Vacuum



Ground Processing Software

DRP	Task	Inputs	Outputs	Complexity	Comments
Raw Data Record	Decode Unpack Decompress Reformat Merge	Time-Tagged Raw Sensor Data Spacecraft Ephemeris/Attitude	Formatted RDR	Low Complexity Well Understood	Need Definition of Input Sensor Data Format
Temperature Data Record	Calibrate Geolocate Polarization Alignment	RDR Static Surface Data Base Sensor Constants File	Calibrated, Surface Tagged, Brightness Temps	Software Heritage SSM/I	Major Function Well Understood Leverage SSM/I and SSMIS experience
Sensor Data Record	Antenna Pattern Correction Beam Averaging Resampling	TDR Sensor Constants File	Calibrated, Referenced, Brightness Temps	Software Heritage SSM/I	Major Function Well Understood Leverage SSM/I and SSMIS experience

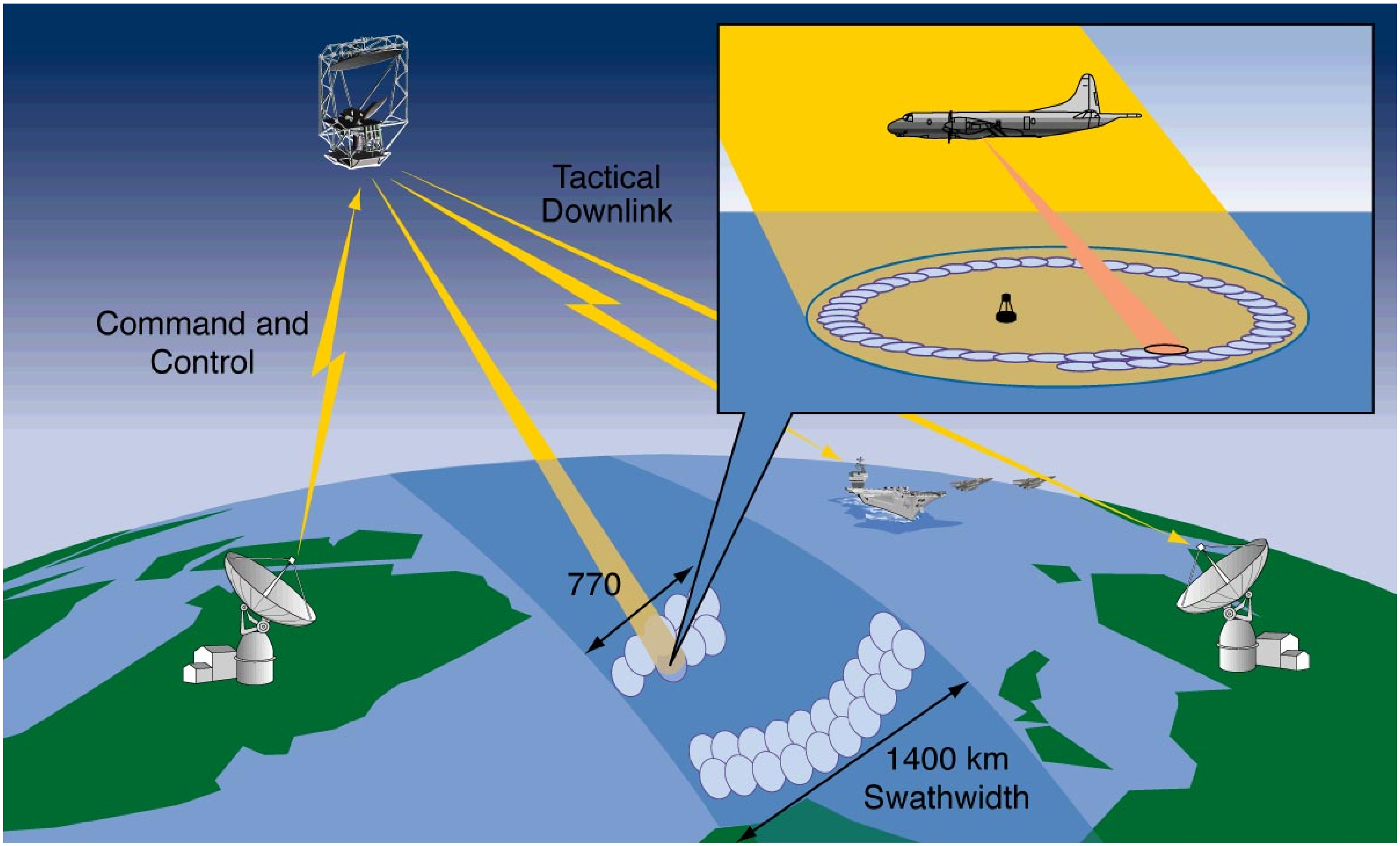
Post-Launch Calibration

- **Post-Launch**
  - **System Calibration**
    - **Gain Stability / System Noise**
      - **Statistical Analysis**
        - Calibration Targets
      - **Uniformity of Samples**
    - **Absolute Calibration Accuracy**
      - **Direct Comparison**
        - Aircraft Data
        - Ground Transmitters (pol)
        - Inter-Sensor Comparison
          SSM/I, SSMIS, TMI, AMSR
      - **Model Comparison**
        - Clear, Calm Ocean
        - Amazon Rainforest
        - Desert Regions
    - **Geolocation**
      - **Image Analysis**
        - Overlay
          Coastline/Island/Lake
      - **Ground Transmitters**
    - **Antenna Main Beam Check**
      - **Boundary Analysis**
        - Land-Water
          Boundaries
  - **System Performance Optimization**
    - **RDRP**
    - **TDRP**
    - **SDRP**

Critical Need:
Absolute Calibration Accuracy

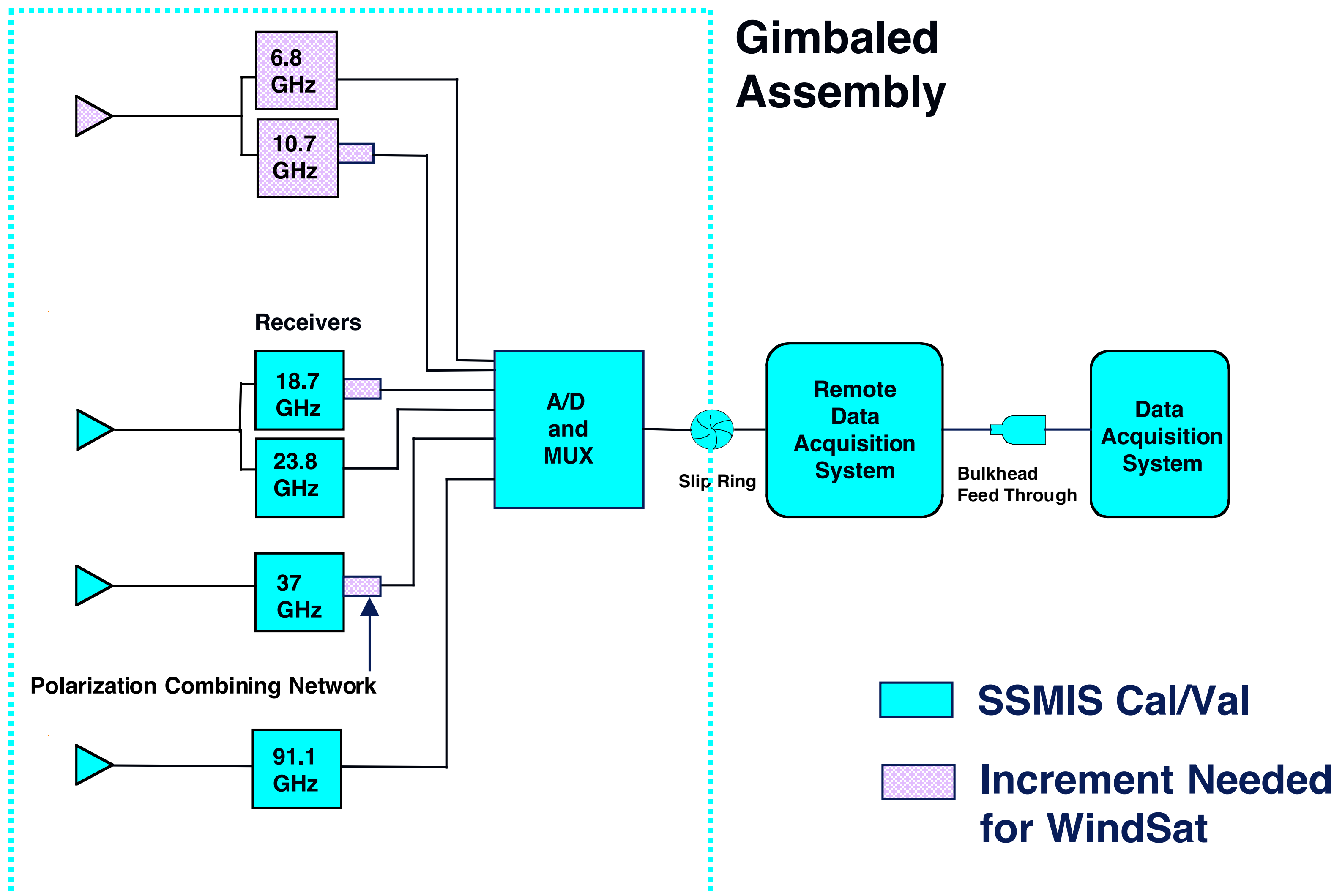
- Direct Comparison of WindSat Measurements With an Independent Source of Brightness Temperature Measurements Is Critical to the Success of the WindSat Program
- Requires a Highly Calibrated, Stable, Polarimetric Radiometer System on an Aircraft Platform; This Approach Proved to Be Successful in the Calibration of the First SSM/I
- NRL Is Building the Airborne Polarimetric Microwave Imaging Radiometer (APMIR), Through Joint Air Force/Navy Funding, to Calibrate the SSMIS (Aug 2000); the Navy Funding Will Also Cover the Modifications Required to Calibrate WindSat
- Other Airborne Systems Are Currently Under Evaluation. Systems Meeting the Accuracy and Sensitivity Requirements May Also Under-fly WindSat, Pending Available Funding

Validation of Brightness Temperatures With the Airborne Polarimetric Microwave Imaging Radiometer (APMIR)

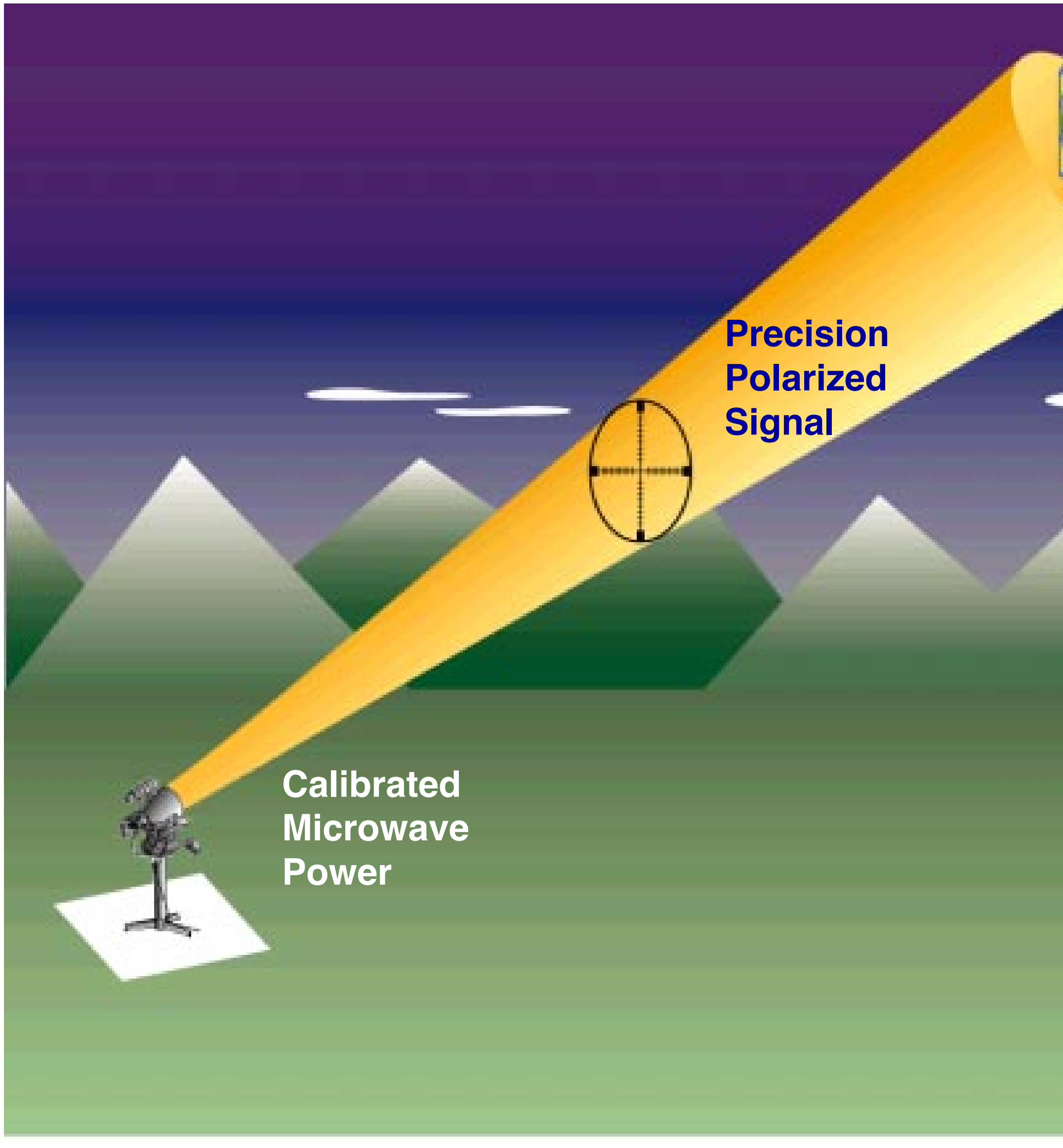


WindSat_swathv5_inset.PCT

APMIR System Block Diagram



Polarization Alignment Calibration



Transmit Power ~ 60mW

Beamwidth = 3°

Alignment Using Star Trackers to .01°

Polarization Rotation Using Inclinometers to .01°

Location: Unpolarized Background

Validation

- Validation
  - Pre-Launch
    - Model/Algorithm Development
      - Wind Vector
        - SST
        - Water Vapor
        - Cloud Liquid Water
        - Rain Flag
  - Post-Launch
    - EDR Validation
      - Wind Vector
        - SST
        - Water Vapor
        - Cloud Liquid Water
        - Rain Flag
    - EDR Algorithm Modification
      - As Needed
      - Environmental Data Record Processor

Pre-Launch Validation Efforts

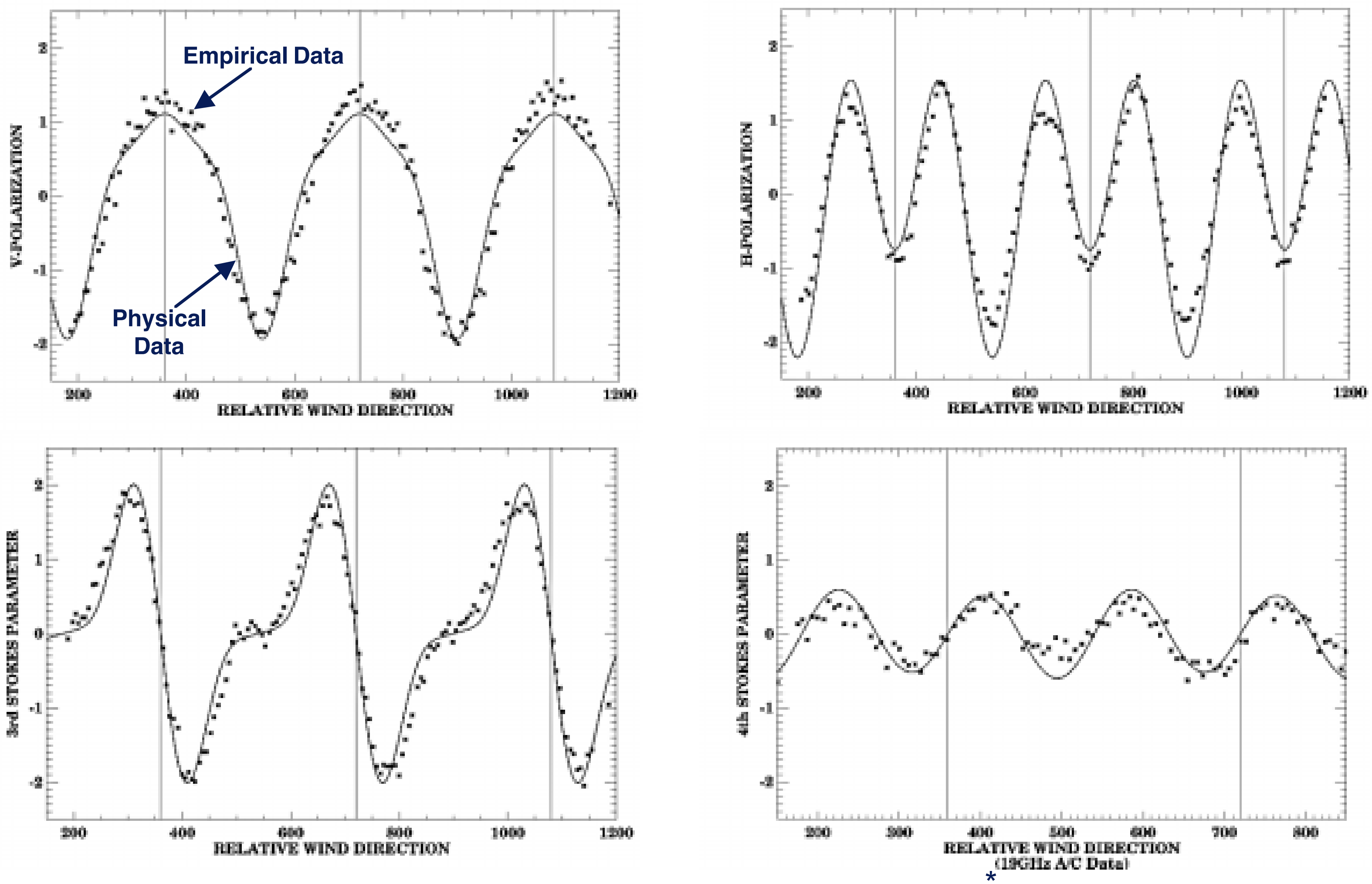
- **Environmental Data Record Algorithms**

EDR	Algoritm Type	Status	Comments
Wind Vector	Statistical	Prelim. in Place	Based on Empirical Model + errors*
	Neural Network	Trial on A/C Data New Start	Based on Empirical Model + errors*
	Physical	In Progress	Based on Physical Models
Supporting Parameters SST, WV,CLW, Rain Flag	Statistical/ Iterative	Prelim. in Place Modified SSM/I Further Dev. For Iterative Routine	Based on Empirical Model With Decision Routines
	Neural Network	New Start	Based on Empirical Model + errors*
	Physical	New Start	Based on Physical Models

* **Representative of Anticipated System Errors Plus Variability in the Environmental Signal**

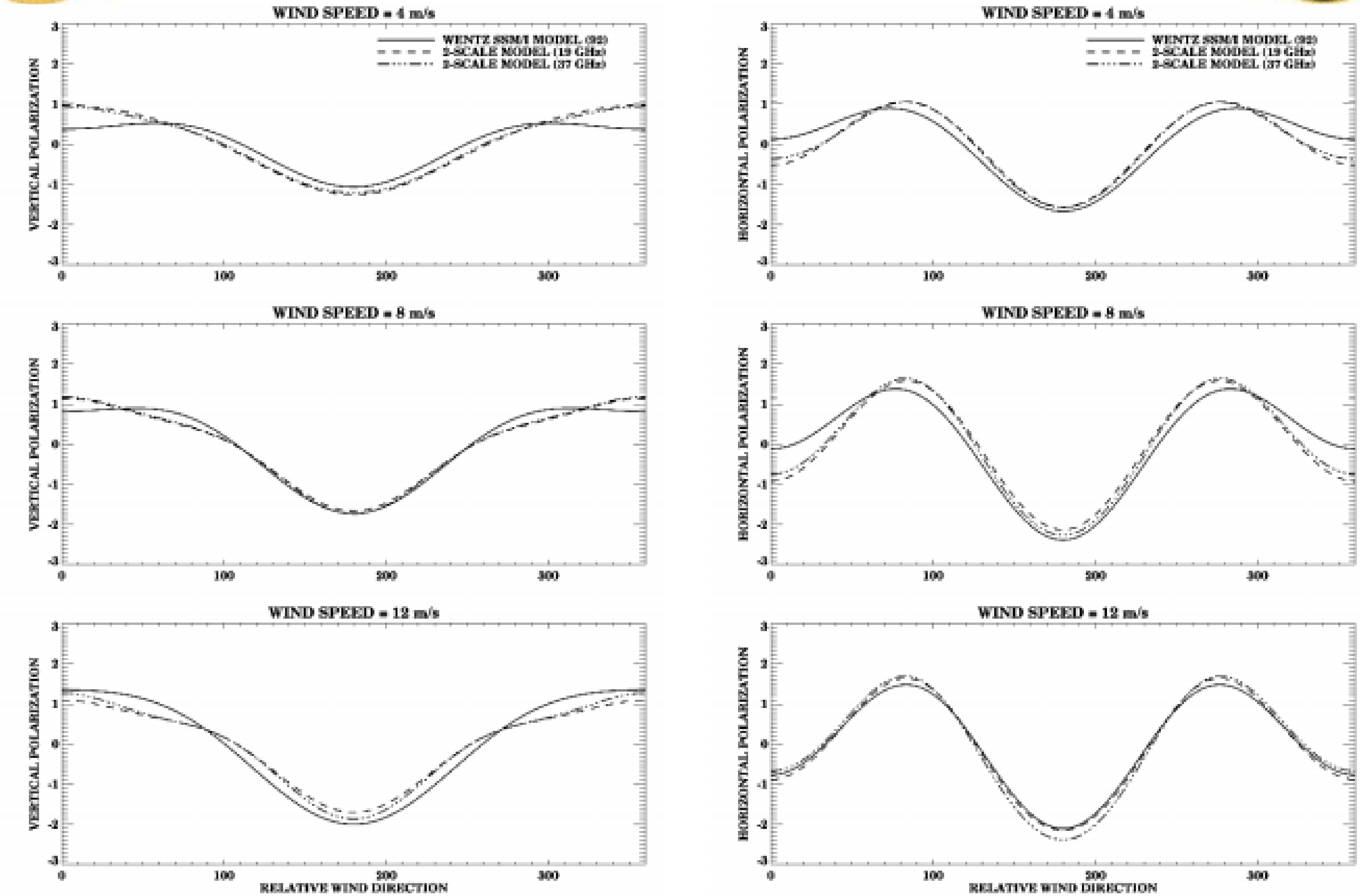
Comparison of Physical Model With Empirical Data

- **37 GHz Aircraft Measurement at 9 m/s Wind Velocity**



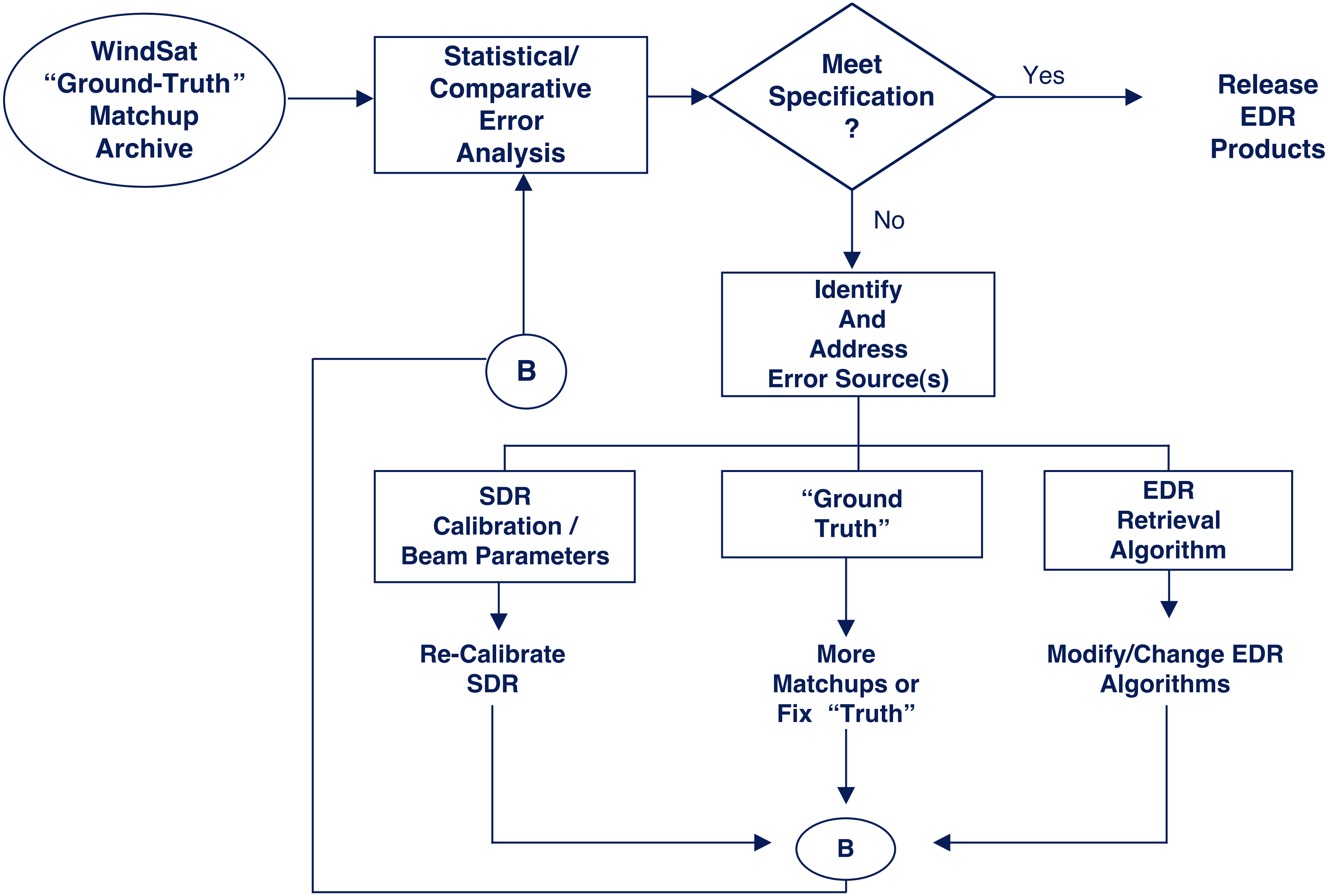
- **Vertical Lines Identify Upwind Direction**
- **Normalized Brightness Temperature (K)**

Comparison of Wentz SSM/I Model and 2-Scale Model

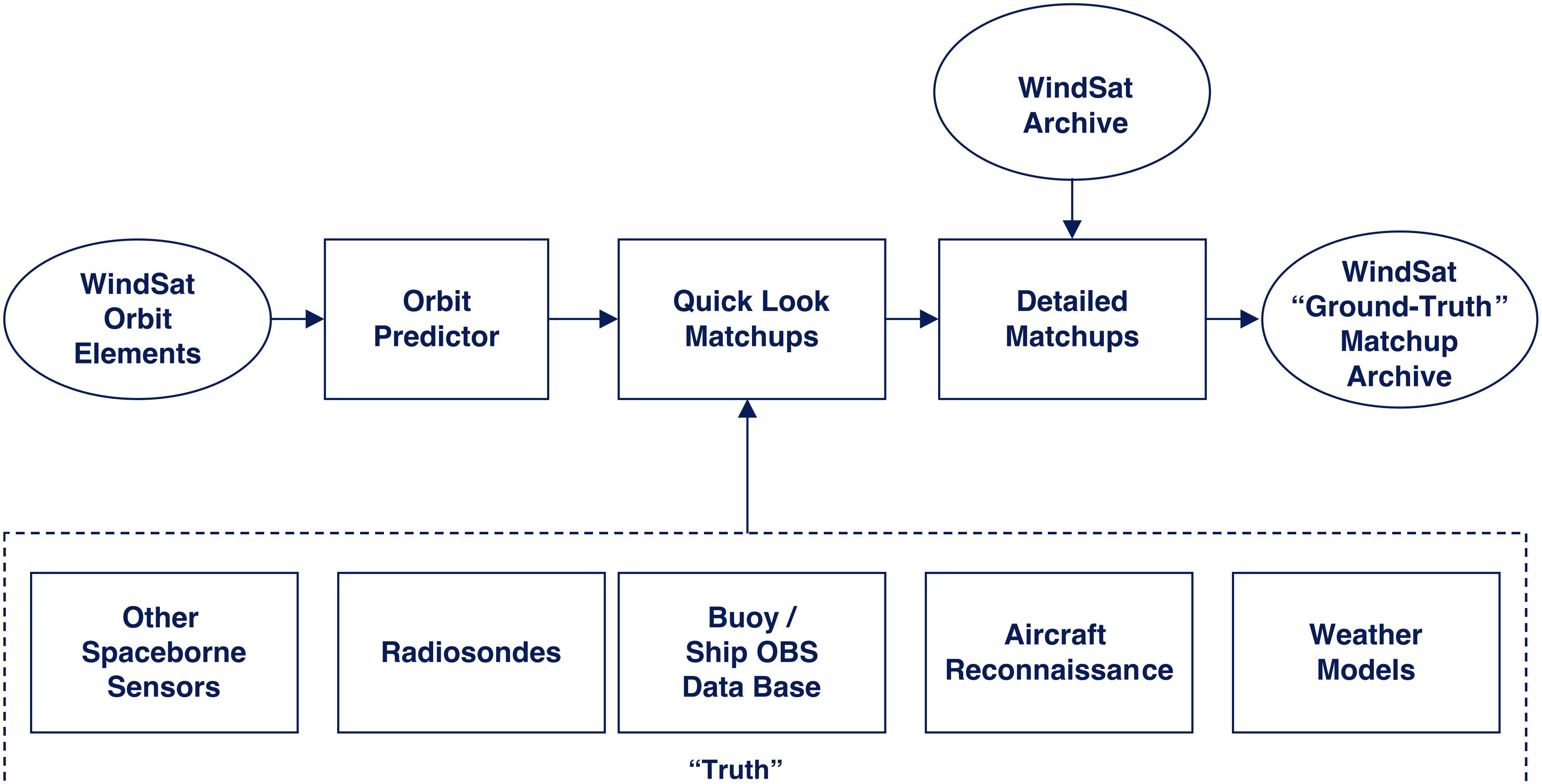


- **Physical Model Representation of Space Based Data**

WindSat Post-Launch EDR Validation Concept (1 of 2)



WindSat Post-Launch EDR Validation Concept (2 of 2)



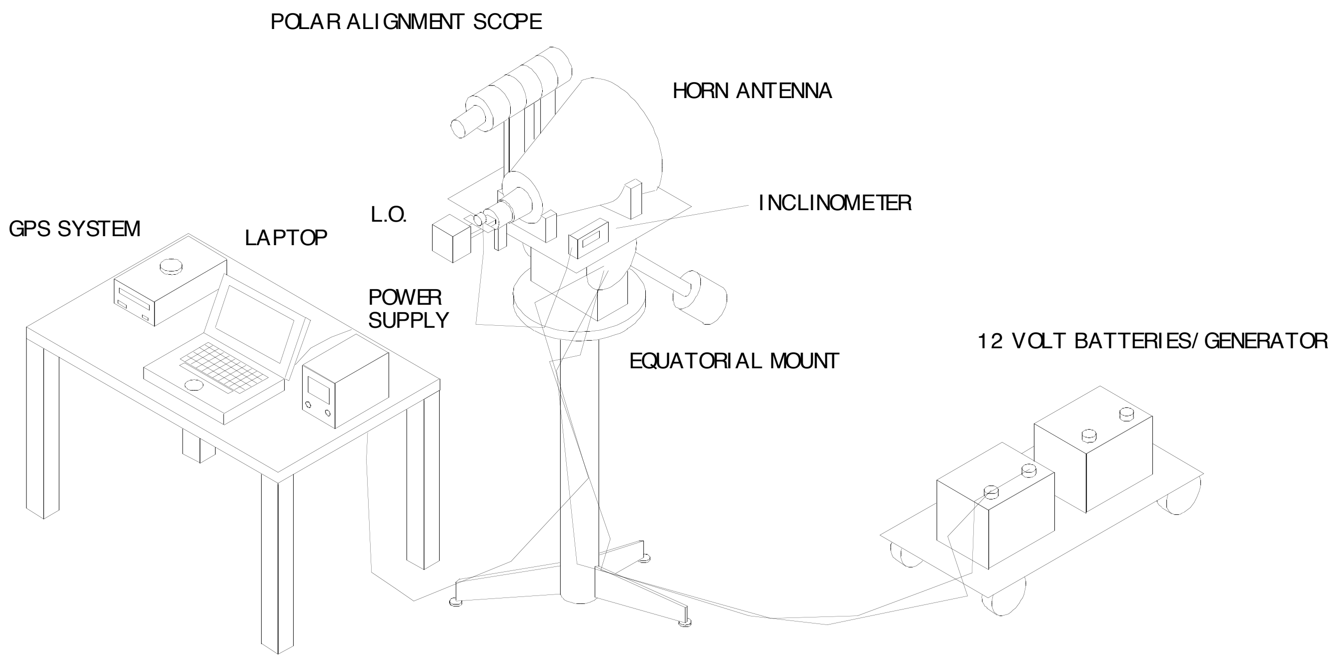
Backup

Wind Vector EDR Validation

- The NOAA National Data Buoy Center Network of Buoys
  - Wind Speed ± 1 m/s
  - Wind Direction ± 10°
  - Data Is 8 Minute Average Reported Every Ten Minutes
  - Buoys Also Provide Sea Surface Temperature, Air Temperature, Surface Pressure, Wave Height, Wave Period
- GPS Dropsondes (Secondary Source of Truth Used Where Buoys Are Not Available)
  - Provides Wind Vector With ±0.5 m/s Accuracy
  - Also Provides Humidity, Temperature, Pressure Profile for Descent Path

Cal/Val Field Pointing System

WINDSAT POLARIZATION ALIGNMENT SYSTEM



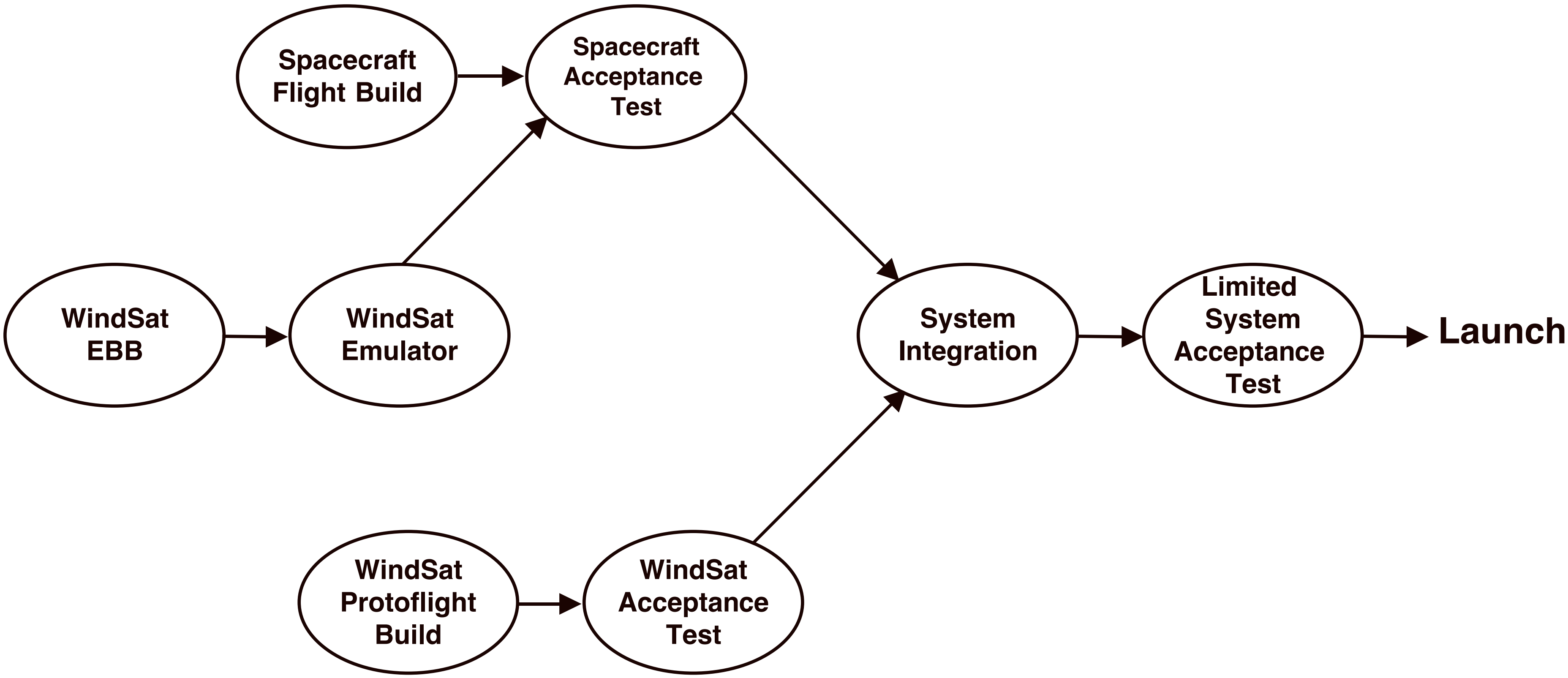
Payload Integration & Test

Purdy

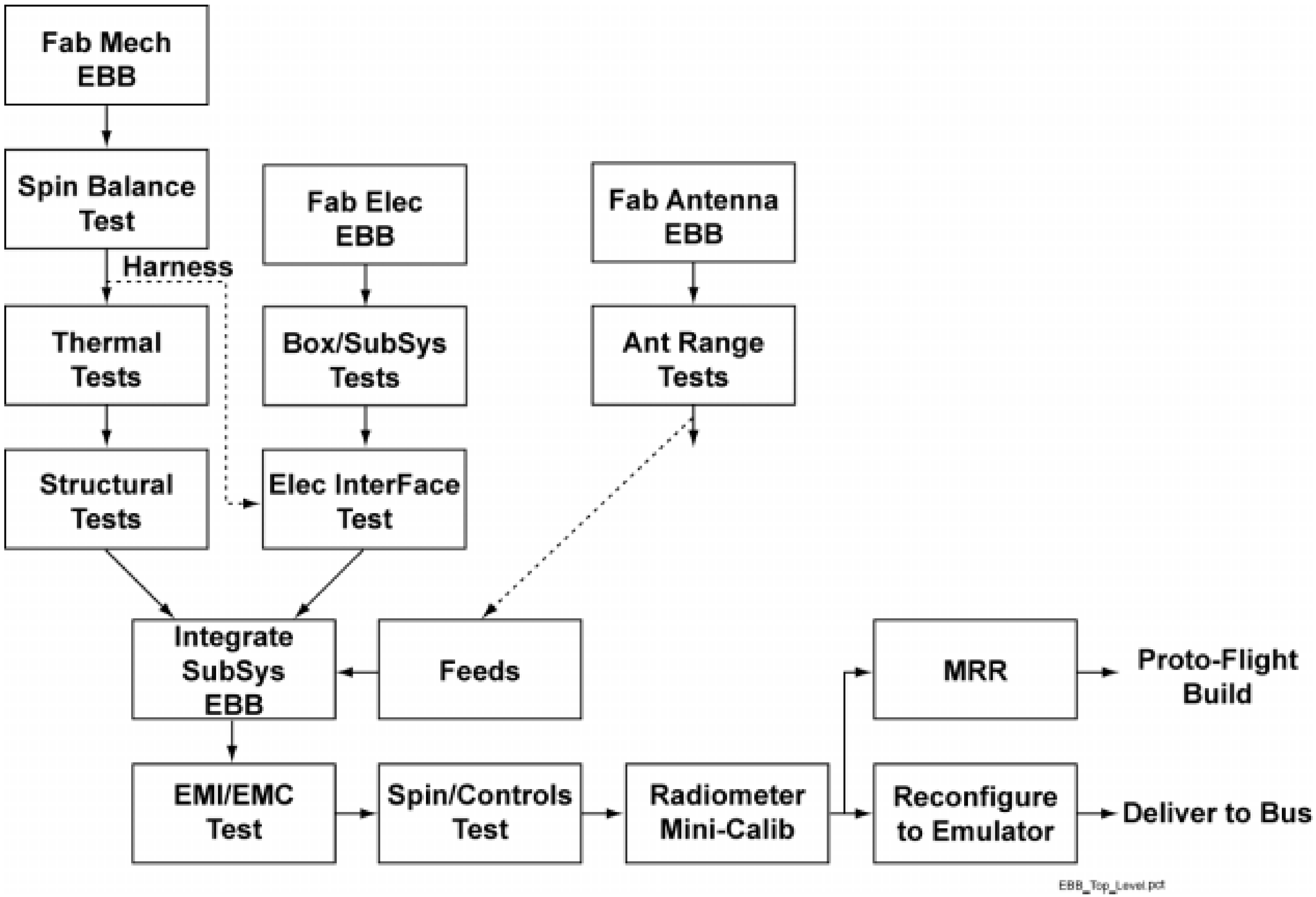
Agenda

- System I&T
- Enhanced Bread Board (EBB) Top-Level I&T
- Mechanical EBB I&T
- Electrical EBB I&T
- Antenna EBB I&T
- Protoflight I&T
- Component-Level Testing

System I&T Flow



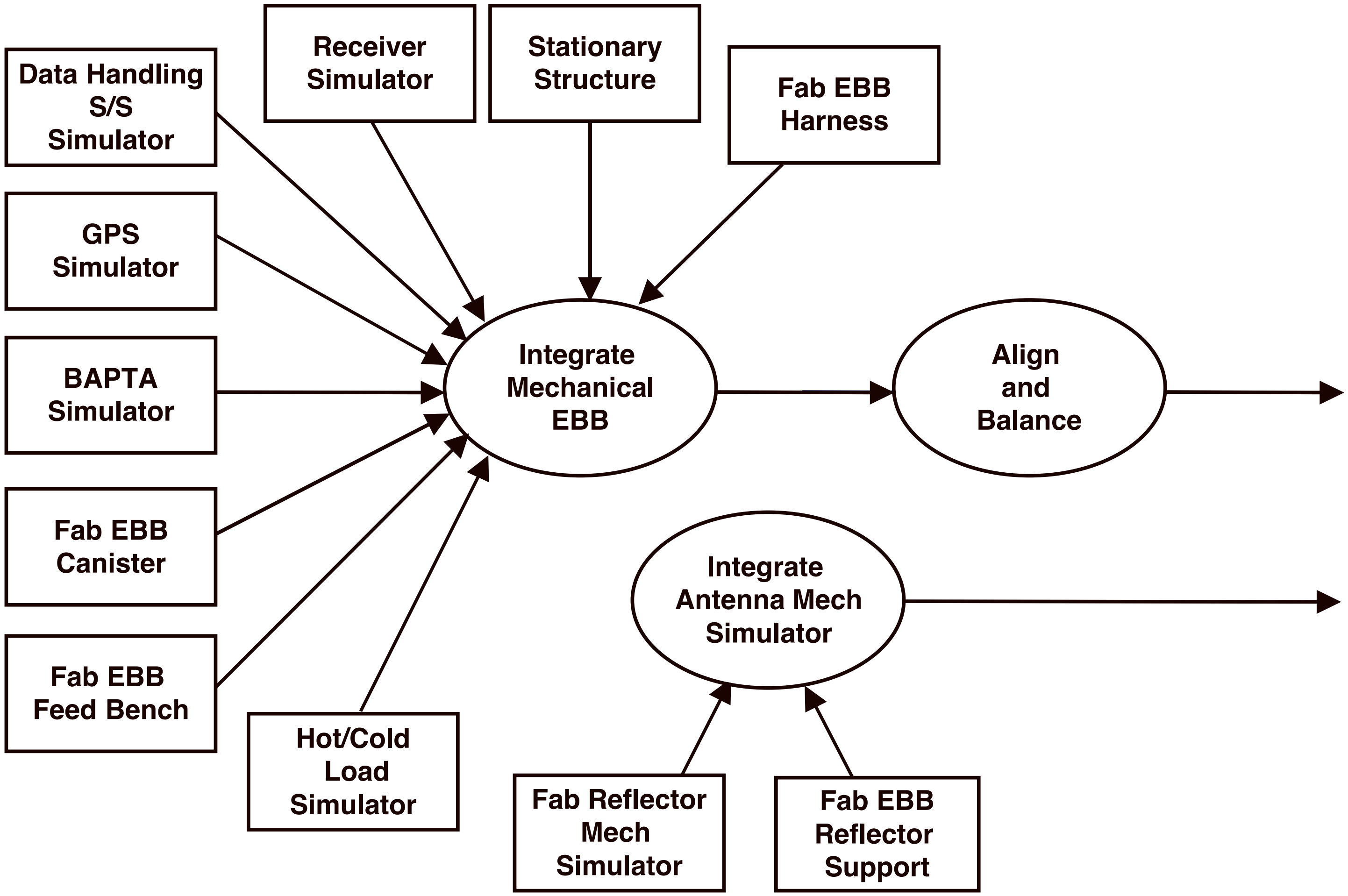
EBB Top-Level I&T



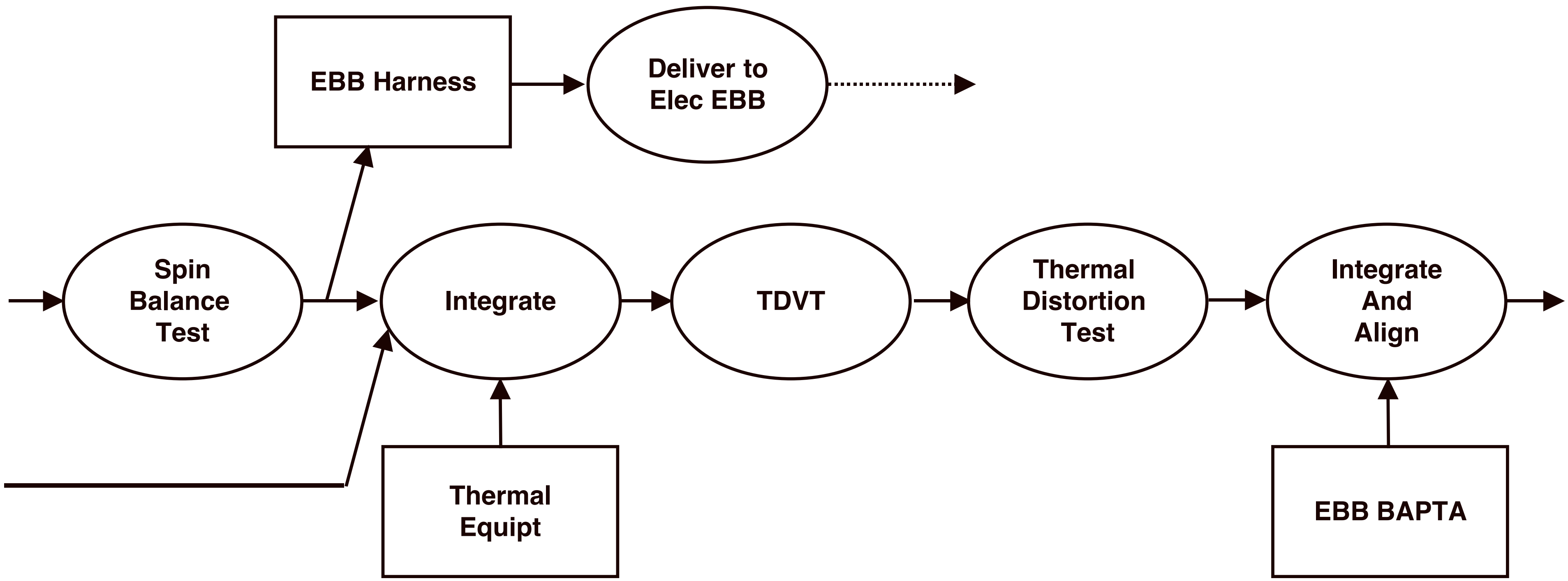
Vehicle Configuration

- Enhanced Bread Board
  - 4/11 Feed Horns (10.7, 37 GHZ)
  - 4/22 Receiver Channels (10.7, 37 GHZ)
  - All DHS Circuits
  - All Structure and Mechanical Equipment
  - Commercial Parts
- Protoflight
  - Protoflight Test Levels
  - Formal Configuration Controls

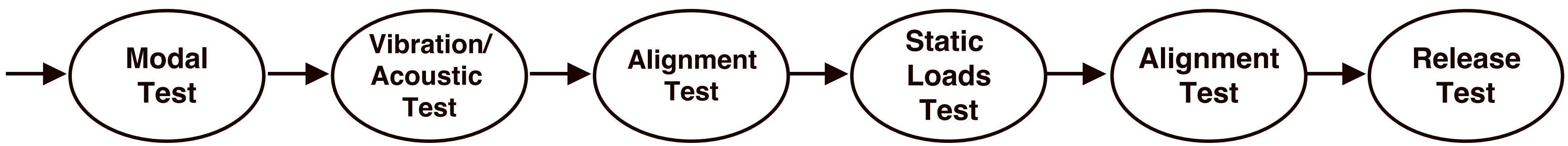
Mechanical EBB I&T (1 of 3)



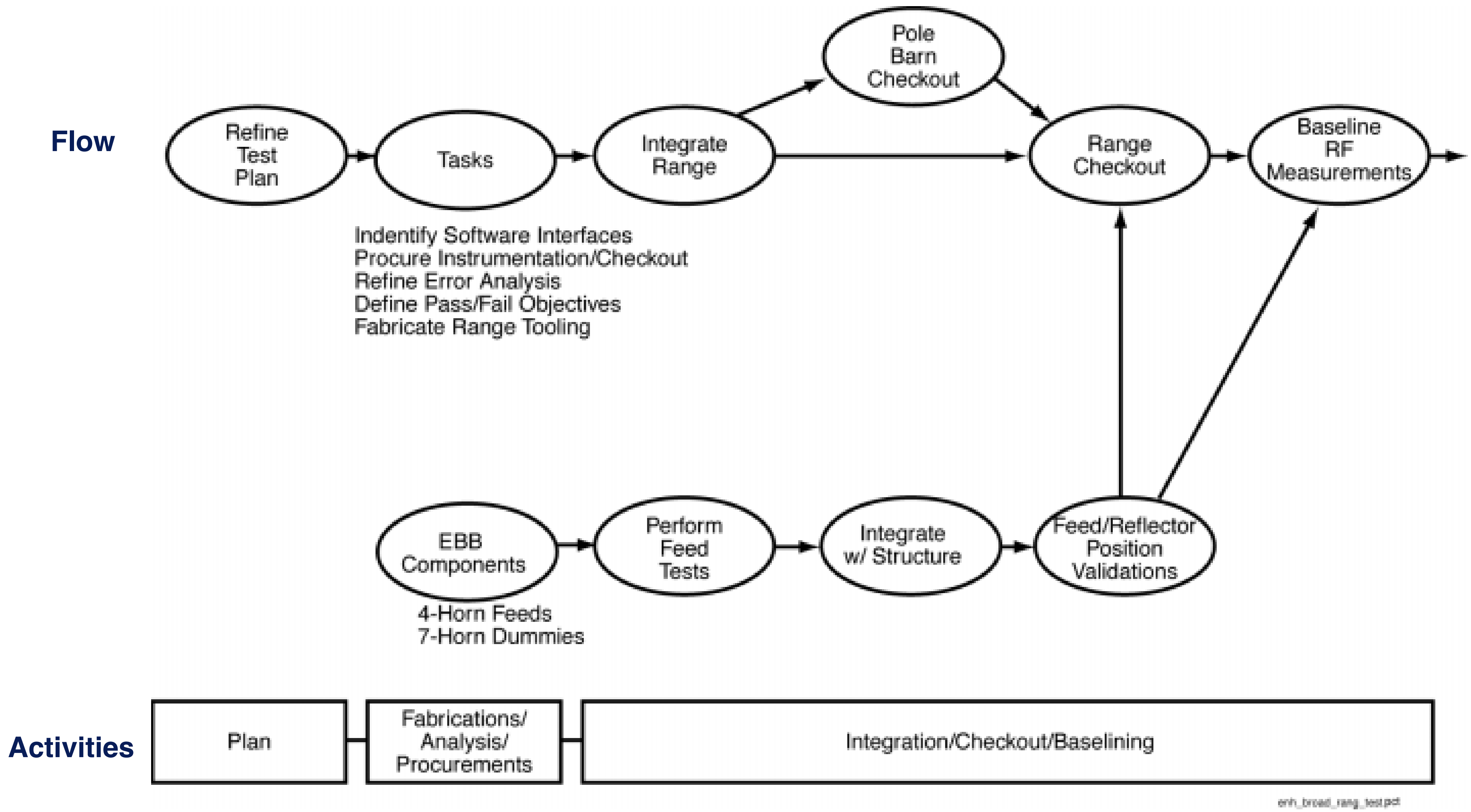
Mechanical EBB I&T (2 of 3)



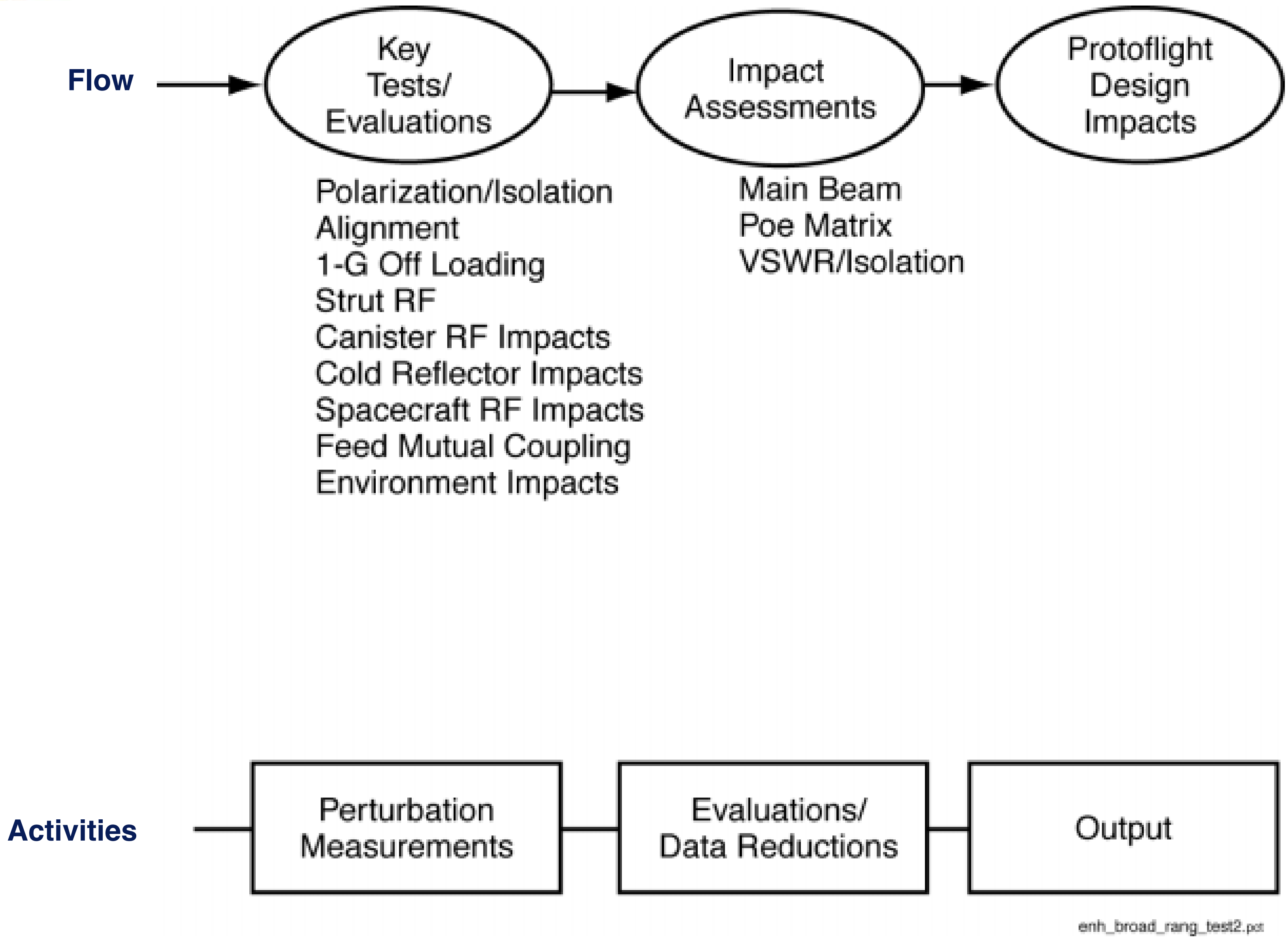
Mechanical EBB I&T (3 of 3)



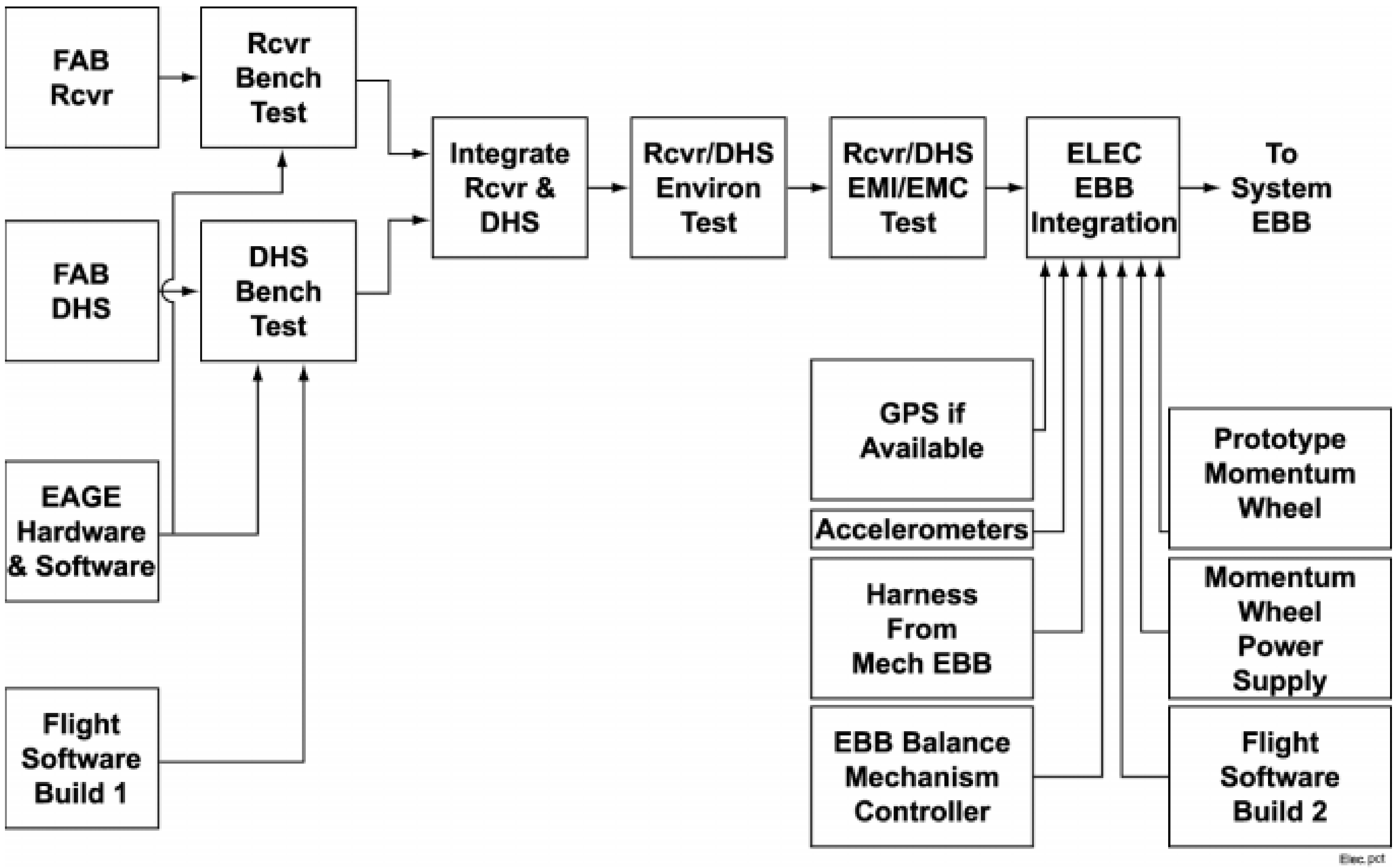
Antenna Range EBB Test (1 of 2)



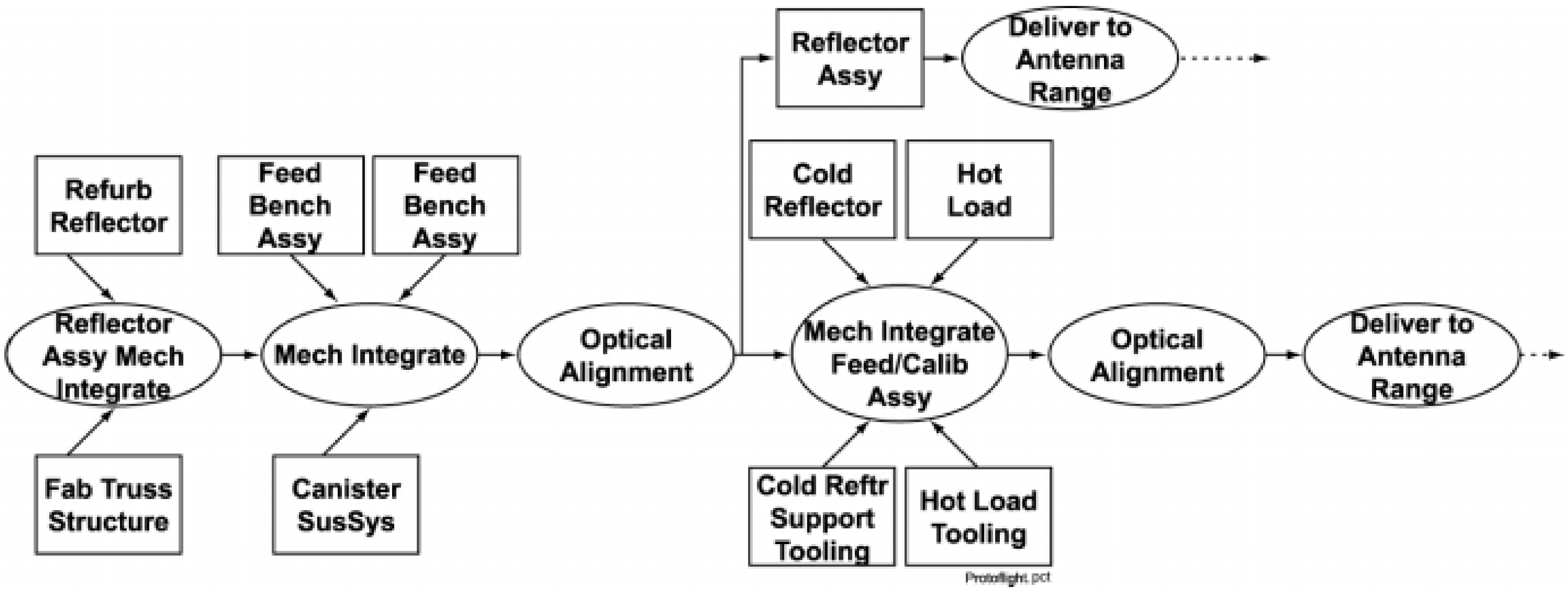
Antenna Range EBB Test (2 of 2)



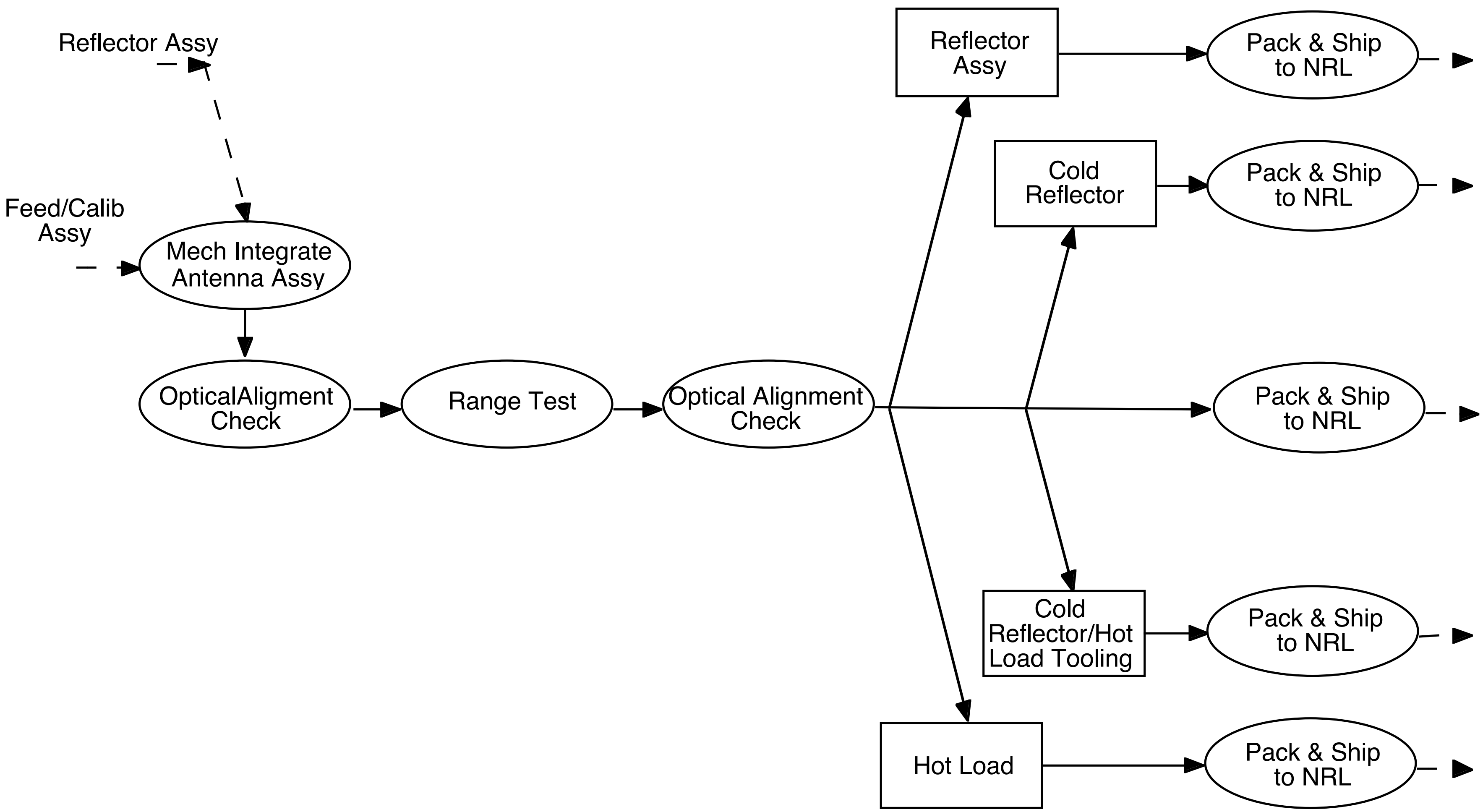
Electrical EBB I&T



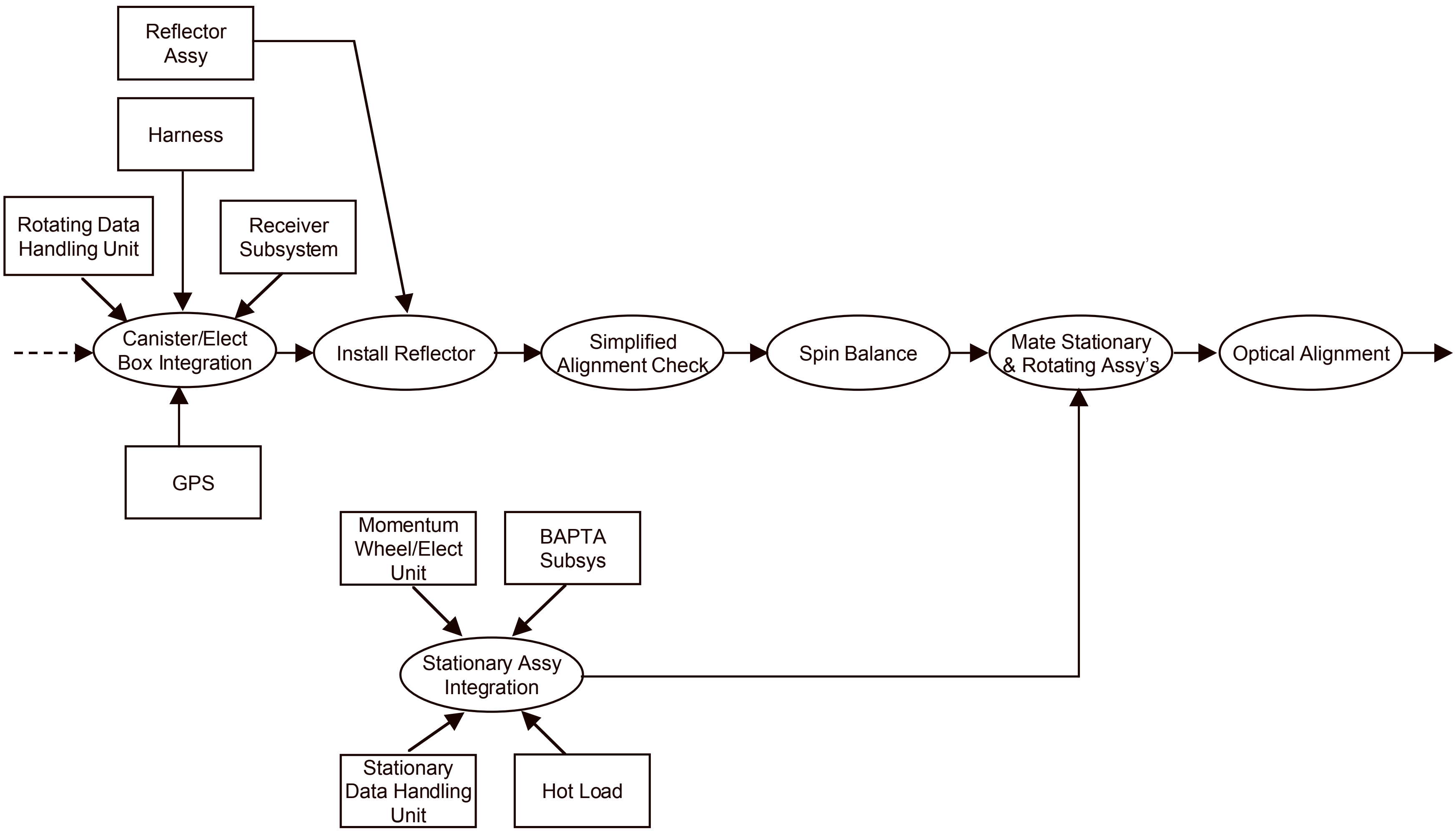
Protoflight I&T (1 of 5)



Protoflight I&T (2 of 5)



Protoflight I&T (3 of 5)



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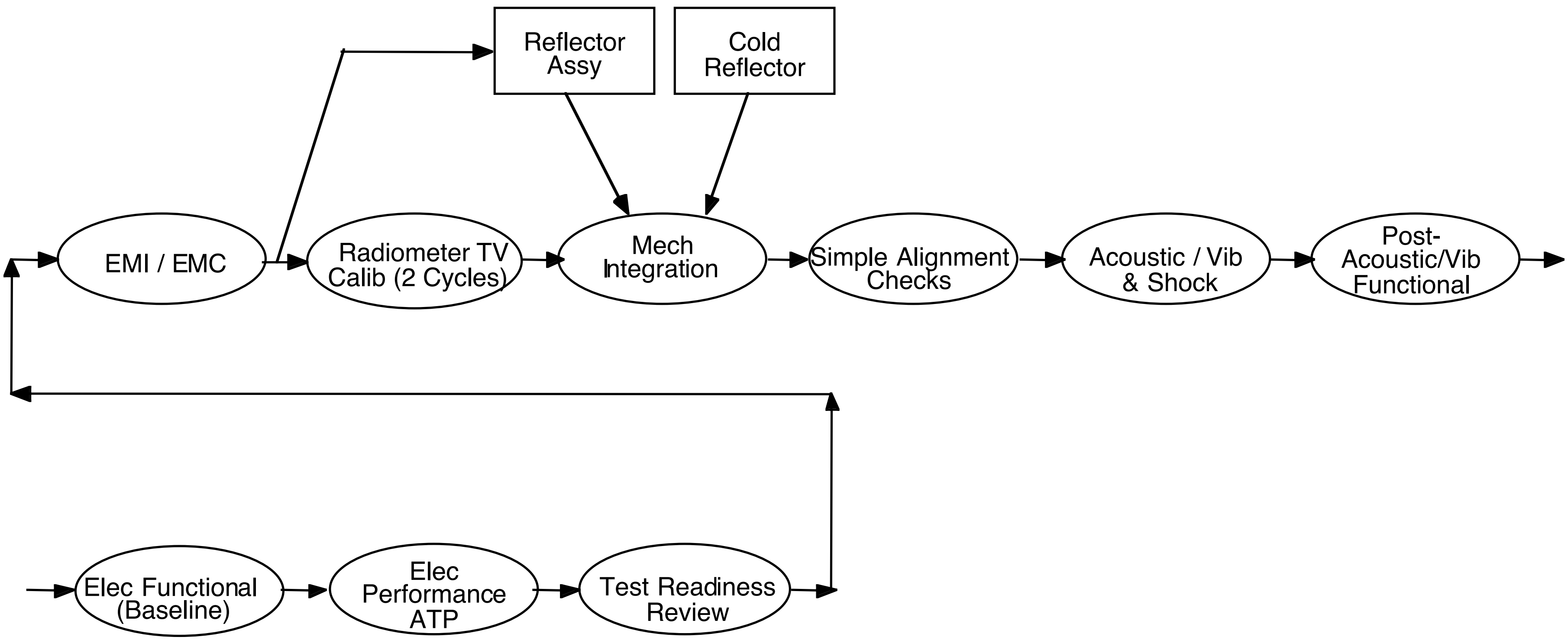
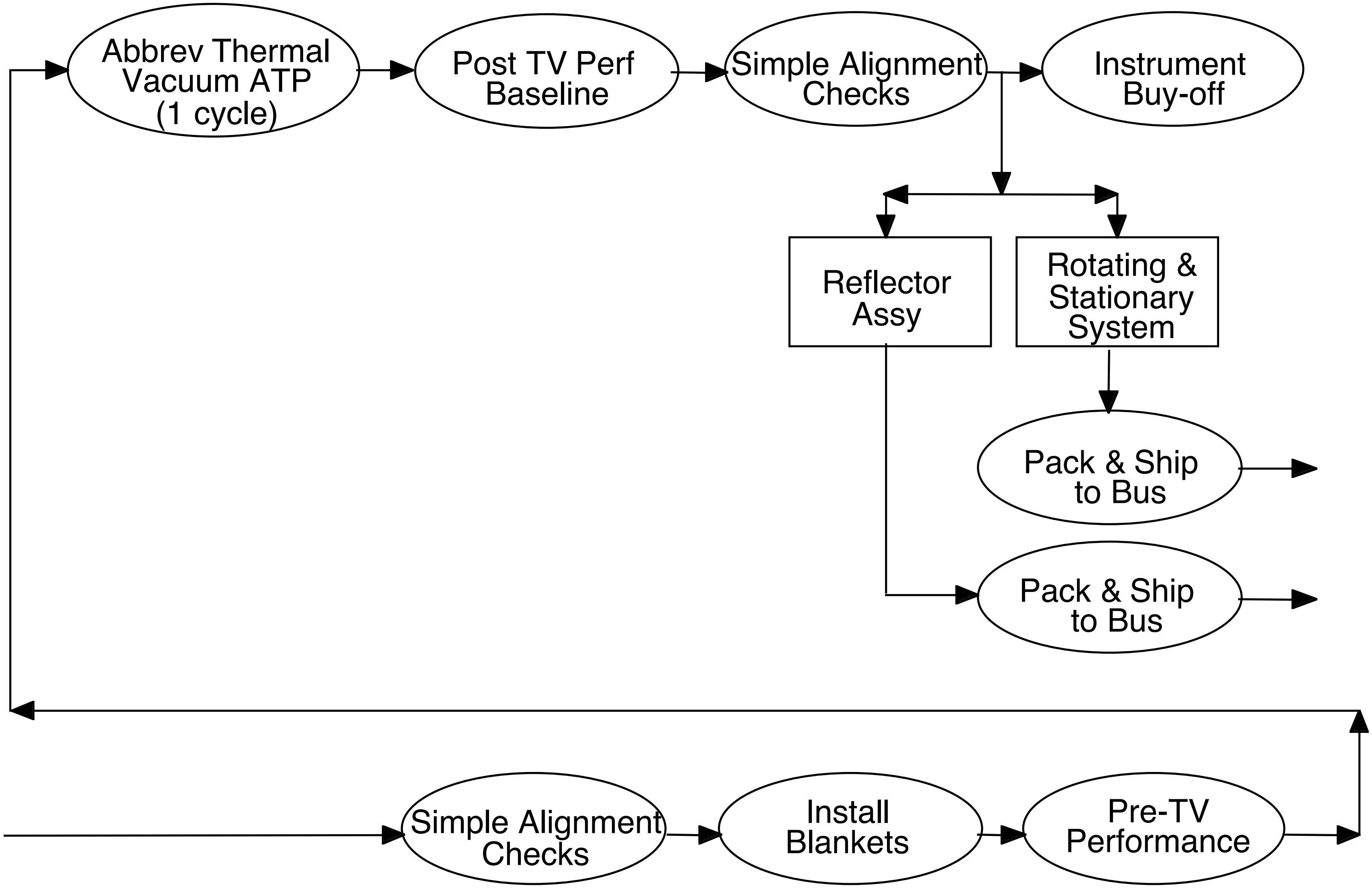
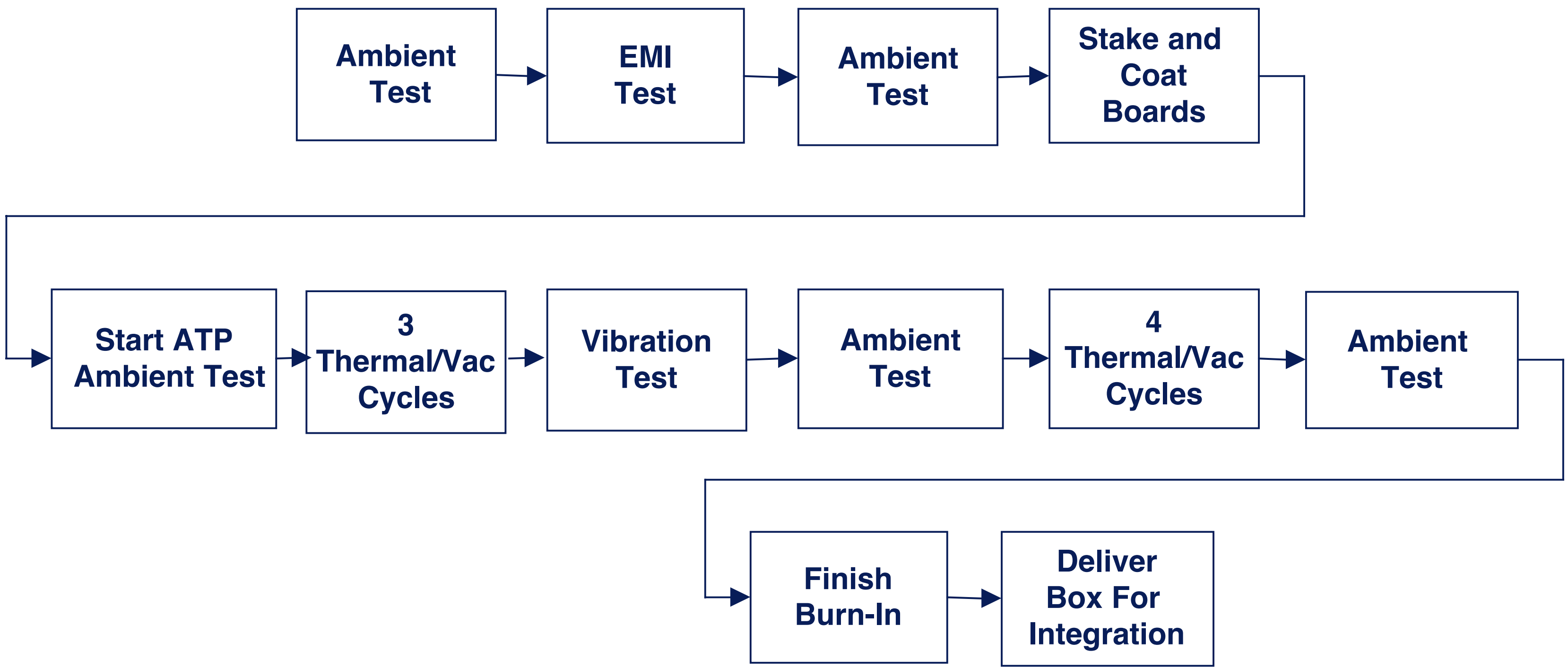


Protoflight I&T (5 of 5)



Component-Level Testing



- 1st and Last Cycle Are 0 to 40 °C
- Mid Cycles Are -20 to 60 °C
- 2 Hour Dwells

Total of 200 Hours Burn-In

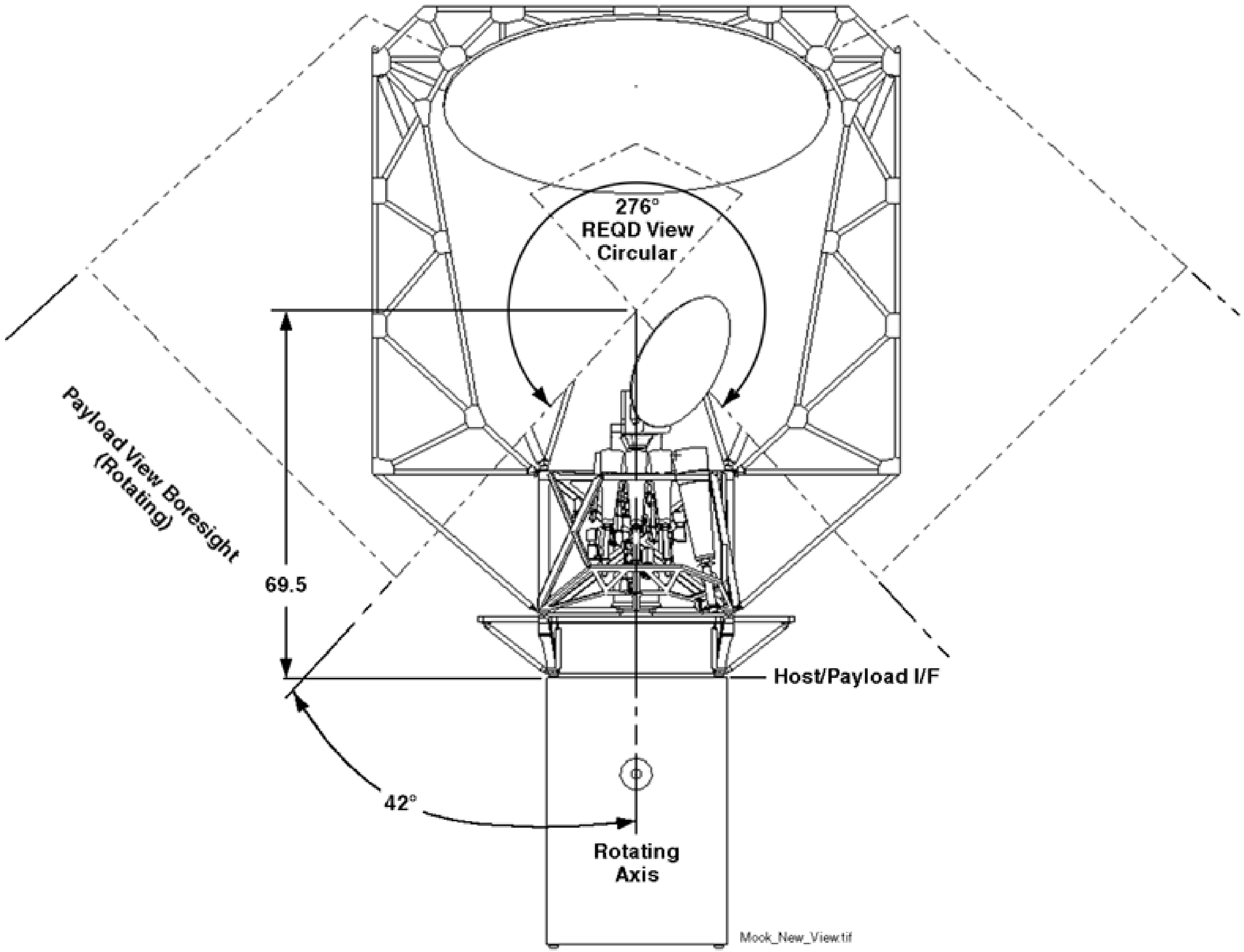
WindSat to Spacecraft Interface

Mook

WindSat to Spacecraft Interface

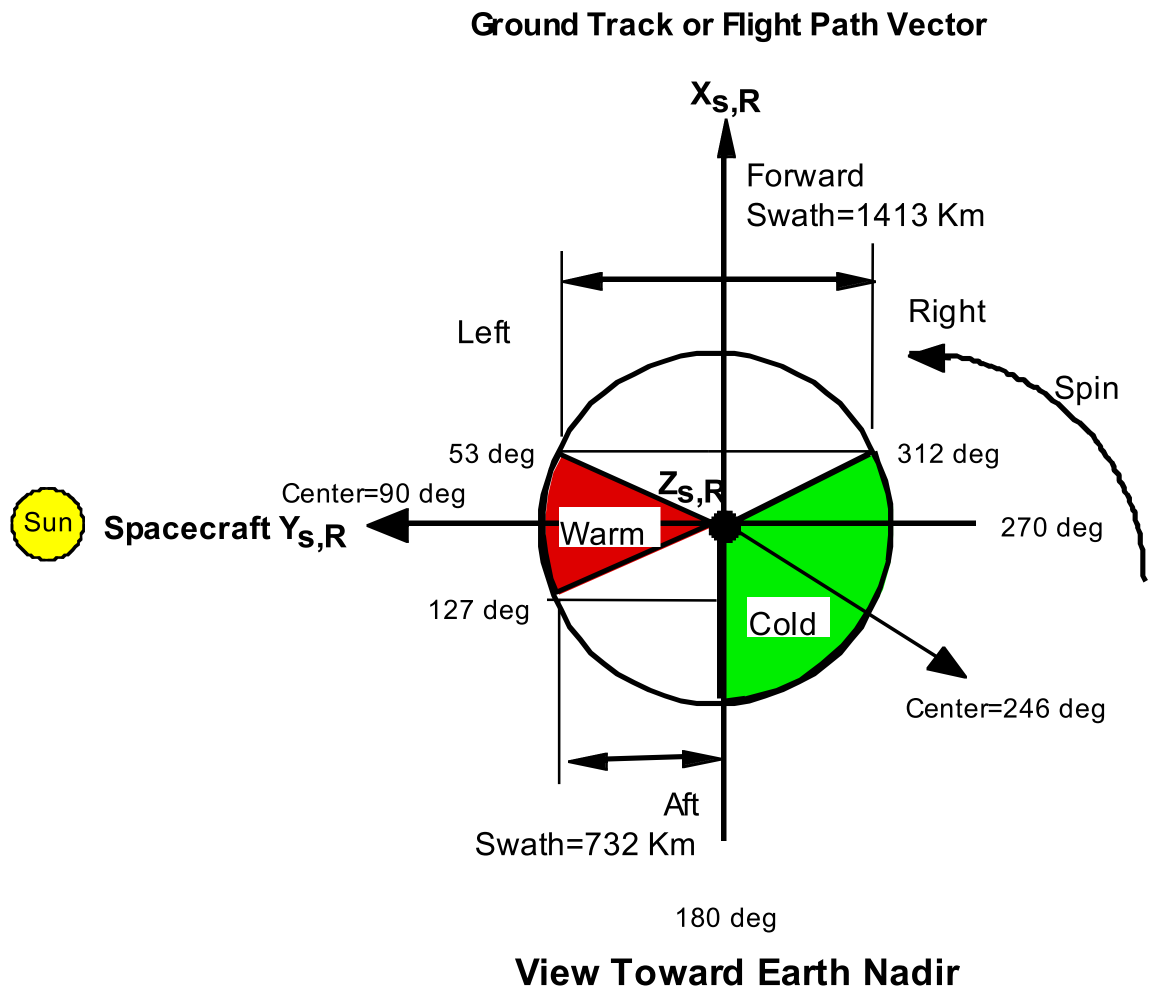
- Physical Interface
  - Field of View
  - Spin Direction
  - Mechanical Interface
  - Forces, Torques and Angular Momentum
- Electrical Interface
  - Electrical Interface Diagram
  - Power Interface
  - Signal Interface
  - Data Interface

WindSat to Spacecraft Interface
Field of View (1 of 2)

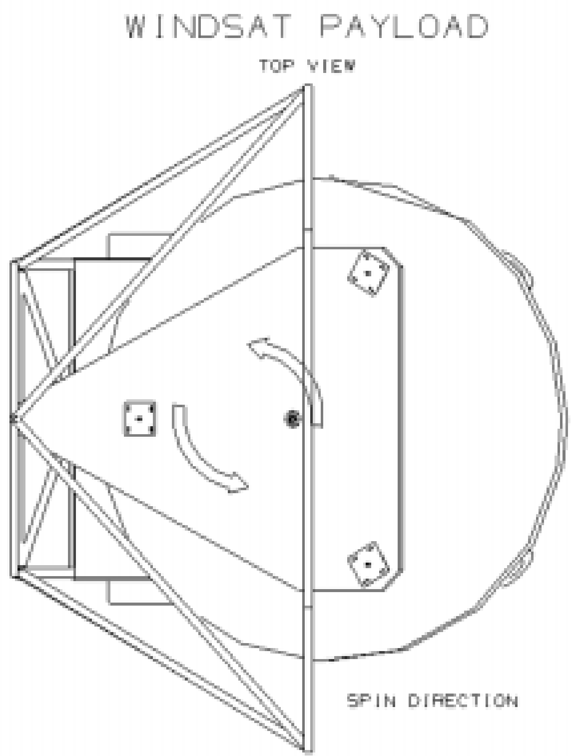


WindSat to Spacecraft Interface Field of View (2 of 2)

- WindSat Main Beam is Blocked by Warm and Cold Loads
- This is Exception to Previously Shown Keep Out Zone



WindSat to Spacecraft Interface
Spin Direction



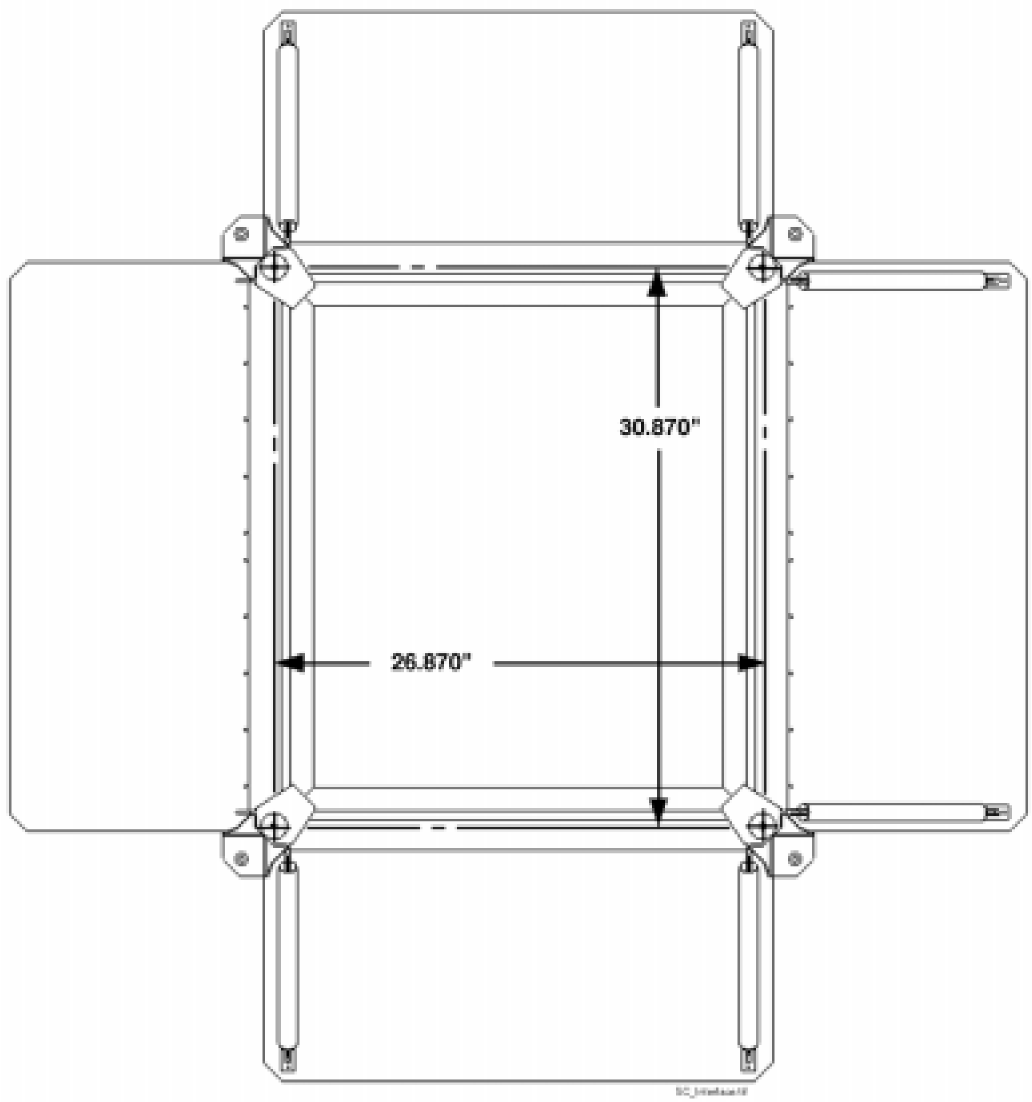
WindSat to Spacecraft Interface
Mechanical Interface (1 of 3)

- The WindSat Payload Requires Mounting to the +Z (Zenith) Side of a Nadir Pointing Spacecraft
- Electrical Connections Will Be Made at a Single, Fixed Interface Panel, the Location of Which Will Be Decided by the Payload and Spacecraft
- The Structure of the Payload and the Spacecraft Will Resolve the Following:
  - Design of Deck;
  - Bolt Pattern;
  - Stiffness Range;
  - Minimum Strength;
  - Coefficient of Thermal Expansion (CTE);
  - Flatness; and
  - Electrical Grounding
- All Structural Modes of the Vehicle (Combined Payload and Spacecraft) While in the Deployed Configuration Will Be Greater Than 5 Hz

WindSat to Spacecraft Interface Mechanical Interface (2 of 3)

- The Payload and Spacecraft Together Will Define and Verify Interface Strength and Loads, and Support Booster Coupled Loads Analyses
- All Combined Vehicle Structural Modes, While in the Launch Configuration, Shall Be Such That:
  - The Primary Lateral Modes Will Be ≥20 Hz for the Payload and ≥25 Hz for the Spacecraft, With the Goal That the Combined Vehicle Lateral Modes Will Be ≥15 Hz.
  - The Primary Axial Modes Will Be ≥40 Hz for the Payload and ≥50 Hz for the Spacecraft, With the Goal That the Combined Vehicle Axial Modes Will Be ≥30 Hz
- The Spacecraft Must Provide Access to an Alignment Reference (I.E., An Alignment Cube) Which Serves to Define the Orientation of the Bus Mechanical Interface
- The Payload to Spacecraft Mounting Must Be Such That the Alignment Will Not Change More Than 0.005 Degrees Along Each Axis Over the Life of the Mission Including Launch
- Both the Spacecraft and the Payload Will Maintain Their Interfaces Between 0˚C to 40˚C (and -20˚C to 60˚C When Payload Is Inactive) Regardless of the Others Temperature

WindSat to Spacecraft Interface
Mechanical Interface (3 of 3)



WindSat to Spacecraft Interface
Forces, Torques, And Angular Momentum

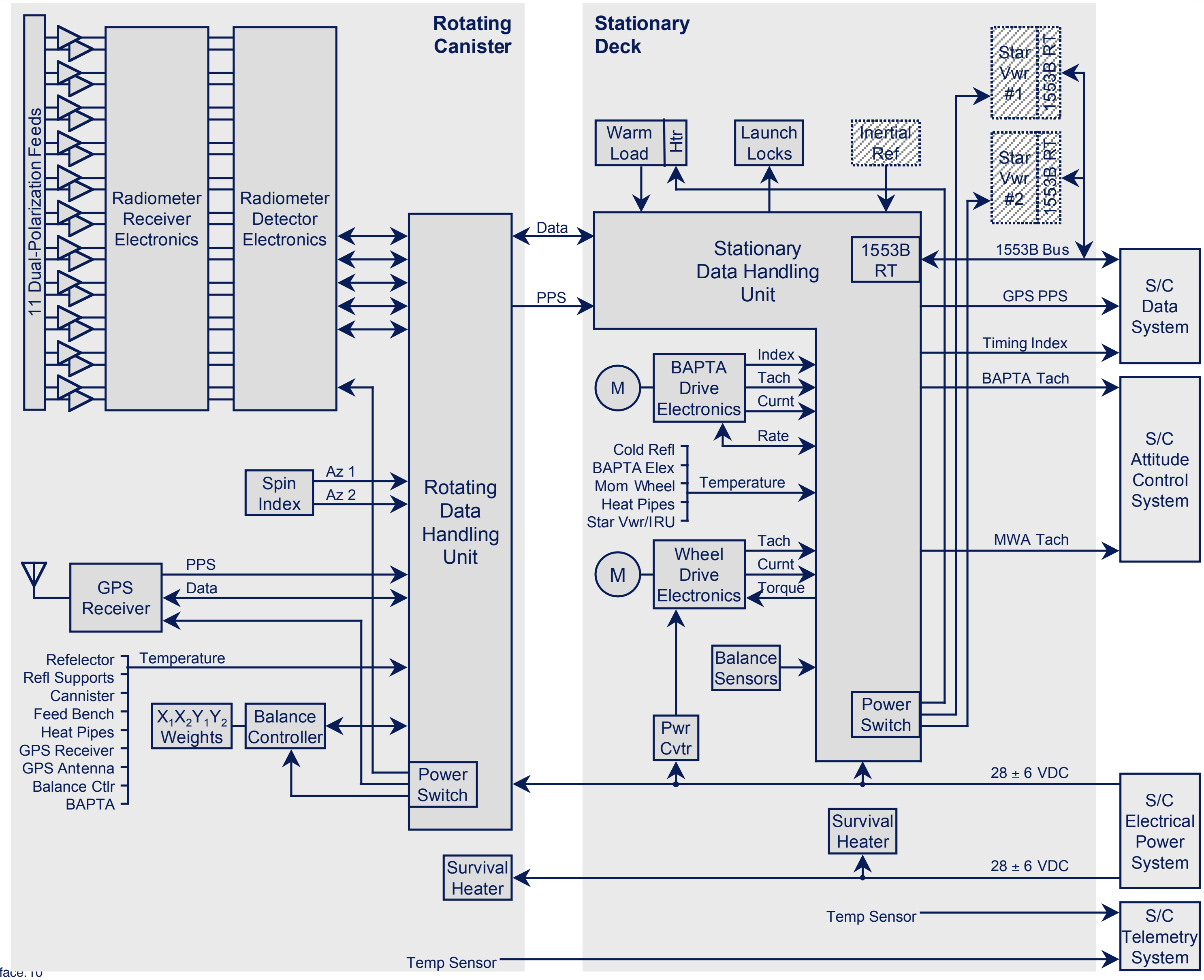
- Payload Forces and Torques Significant to the Gross SC Motion Are Due to BAPTA and MWA Operation and Mass Imbalance

- The Mass Imbalance Will Be Determined and Trimmed On-orbit
  - Static Imbalance (Trimmed) <0.1 lbm-ft
  - Dynamic Imbalance (Trimmed) <0.1 lbm-ft^2

- Largest Residual Torque Will Occur During BAPTA/MWA Spin up and Spin Down
  - Torques Can Exceed 0.2 N-m but Only for Brief Periods

- The SC Bus Control System Will Need to Absorb Residual BAPTA/MWA Angular Momentum
  - Peak Residual Momentum May Exceed 3 N-m-s

WindSat to Spacecraft Interface Electrical Interface Diagram



WindSat to Spacecraft Interface
Power Interface (1 of 2)

- Electrical Power Shall Be in the Range of 22 Vdc to 34 Vdc (Unregulated)
- The Spacecraft Bus Shall Supply Two Sets of Two Switched Power Interconnects to the WindSat Payload. Active Power Will Be Supplied Through One Set of Interconnects or the Other, but Not Through Both Simultaneously
- The Spacecraft Bus Electrical Power System Shall Be Capable of Supplying 429 Watts (This Includes 40% WindSat Design Margin but Is Exclusive of the Survival Heater Power) to the Operating Payload
- The Spacecraft Bus Power System Shall Tolerate Stepped Changes in the Power Load
- Switched Electrical Power Shall Be Supplied to the WindSat Payload Survival Heating Assembly Through a Separate Power Interface, Also Operating at 22 Vdc to 34 Vdc
- Power Shall Be Applied to the Survival Heaters at All Times; When WindSat Is Operating the Survival Heaters Will Not Dissipate Any Power

WindSat to Spacecraft Interface
Power Interface (2 of 2)

- When Active, the Survival Heater Assembly Will Consume 168 Watts at Nominal Supply Voltage of 22 Vdc

  – DC Resistance Heaters Current Will Increase with Bus Voltage

- Electrical Power Shall Meet the WindSat Electromagnetic Interference (EMI)/electromagnetic Compatibility (EMC) Plan Requirements

WindSat to Spacecraft Interface
Signal Interface

- Bi-Directional Data Interface (1553B)
- Inputs: All Input Signals Are Via 1553B (Command & Data)
- Outputs:
  - 1553B
  - RS422
    - 1 PPS GPS Signal
    - Timing Index Mark (TIM) From SDHU
    - BAPTA Encoder*
    - MWA Tach*
    - Secondary Supply Voltages From SDHU*
  - Analog
    - Two Thermistor Connections**

*   Available Anytime Power Is Applied To WindSat

** Available (And Must Be Monitored) When WindSat Is Off

WindSat to Spacecraft Interface
Data Interface

- WindSat Command & Data Rates
  - Data Rate < 300 Kbps

- S/C Data Bulk Storage Requirements
  - FIFO Storage
  - Sized To Provide 24 Hrs Data To SOC Each Day (I.E., Contact Dependent)

- Bus Data Required
  - Star Tracker & Rate Sensor Data
  - Attitude Estimation
  - Estimated Control Forces & Torques
  - Mass Properties (Changes Due to Fuel Use)
  - Command Execution Log (Time Line)

WindSat On-Orbit Operations

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WindSat On-Orbit Operations
Constraints

- Tip Off, Spacecraft Initial Acquisition, Orbit Acquisition, Attitude Acquisition & SC Bus Checkout:
  - Survival Heaters On Within 120 Minutes After Launch
  - No Requirement To Activate Payload Until After SC Bus Checkout
- At All Times:
  - The Sun Shall Not Remain on the Reflector Face for Periods Exceeding 30 Minutes
  - The Antenna Struts Shall Not Remain Shaded for Periods Exceeding 90 Minutes

WindSat On-Orbit Operations
Phase I : Post Launch Checkout (1 of 2)

- Payload Turn-on (Power Up) & Initialization Sequence
  - Bus Switches On Power (On One Of Two Connections)
  - SDHU Powers Up First
  - Verify 1553 Comms
  - Turn on GPS and Initialize
  - SDHU Cmd Sequence Initiated For The Rest Of WindSat
    - P/L Power Up Sequence
    - SDHU System Check Out Sequence
  - P/L Releases WindSat Launch Locks

WindSat On-Orbit Operations
Phase I : Post Launch Checkout (2 of 2)

- Spin Up
  - Spin Up Will Be Initiated Over A Ground Site
  - Spin Up In Steps (First Small And Then Larger)
  - Steps Less The 5 N-m-s Each (< 0.75 RPM)
  - Total Spin Up Duration Will Be Between 1 And 3 Hrs
  - Monitor Performance
- WindSat Checkout
  - Collect Radiometer Data
  - Verify Telemetry Data Formats (E.g., Mixed Radiometer And Pointing Data)
- Trim Mass Properties Of Rotating Payload

WindSat On-Orbit Operations
Phase II : Calibration/Validation

- Cal/Val Operations
  - Maintain Nadir Pointing Orientation
  - Perform Continuous Radiometer Data Collection
  - Perform System Monitoring (Hardware, Control, Error Flags, Etc.)

WindSat On-Orbit Operations
Phase III : Proto-Operational

- Maintain Nadir Pointing Orientation
- Perform Continuous Radiometer Data Collection
- Perform System Monitoring (Hardware, Control, Error Flags, Etc.)
- Direct Broadcast To SMQ-11 Available Continuously
  - Standard Downlink To SOC Still Fully Utilized
- Demonstrate IORD Data Latency Capability

WindSat On-Orbit Operations
Safehold Modes

- Safehold Modes:
  - Key Constraints Are The Solar Array Pointing (Sun Synch Orbit) And The Survival Heaters
  - Reaction Depends On Safe Hold Mode (SHM) Trigger
    - Large Attitude Error
    - Undervoltage Condition
  - If Possible Advance Notice Should Be Given If Despin Is Required (<15 Minutes)
  - If Not Bus Should Allow Yaw Tumble & Cone Until Despin Is Complete

WindSat On-Orbit Operations
BAPTA/MWA Failure Detection & Response

- **SDHU Logic Monitors Both BAPTA & MWA Rates**

- **If Unacceptable Erratic Behavior Is Discovered In One Or The Other (But Not Both) Initiate Despin Procedure (Step Down)**

- **If Failure Is Detected (Uncommanded Despin) Then SDHU Commands Functioning System To Follow Despin**

Range Safety

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Range Safety

- The WindSat Team Is Familiar With Range Safety Concerns, Operations, and Practices
- The Program Hardware and Personnel Will Conform to EWR-127-1
- The Payload Has Identified No Hazardous Materials, Pressure Vessels, Radiation Sources, Ordnance, Or High-voltage Sources
- WindSat Has Not Identified Any Special Handling Requirements but May
- WindSat Will Not Be Susceptible to Range Induced EMI

WindSat Mission Ops

Tim Barock

Steve Montgomery

Status and Schedule

- Schedule
  - Ground Segment PDR Will Move to Payload CDR (12/98) to Better Sequence Work With Satellite Bus Decision. Ground Segment CDR Will Occur at Payload MRR 10/99

- Status
  - Notional Architecture
  - Updated Requirements
  - S-band Interference Mitigation
  - Candidate Systems
  - Tactical and Mission Data Format

Notional Architecture

Ground Segment Architecture Requirements (1 of 2)

WindSat Data Delivery Requirements

Mission Objective	1st Year Cal/Val	2nd Year Operations	3rd Year Operations	Priority
Collect Science Data	**Continuous**	**Continuous**	**Continuous**	**1,3,3**
Demonstrate Mission Data Delivery & Processing	**Continuous**	**Continuous**	**Continuous**	**2,1,1**
Broadcast Demonstration of Tactical Downlink	**Continuous** (Algorithm validation at single site only)	**Continuous** (Available to tactical terminal users)	**Continuous** (Available to tactical terminal users)	**3,1,1**
Demonstrate Mission Data Delivery & Processing in accordance with IORD requirements. (1.25X Orbital Period + 30 minutes)	**Quarterly**	**Monthly**	**Monthly**	**3,2,2**
SOC Location	**TBD**	**TBD**	**TBD**	
POC Location	**TBD**	**TBD**	**TBD**	
Science Evaluation	**NRL/DC**	**NRL/DC**	**NRL/DC**	

Ground Segment Architecture Requirements (2 of 2)

3:1 Compression Versus No Compression

- 3:1 Advantages:
  - Reduced Access Times
  - T1 Landline Sufficient for Backhaul
  - Buffer Capable of Holding 14 Orbits of Information Before Overflow
- 3:1 Disadvantages:
  - More Code Development for Compression / Decompression
  - Increased Data Error Rate

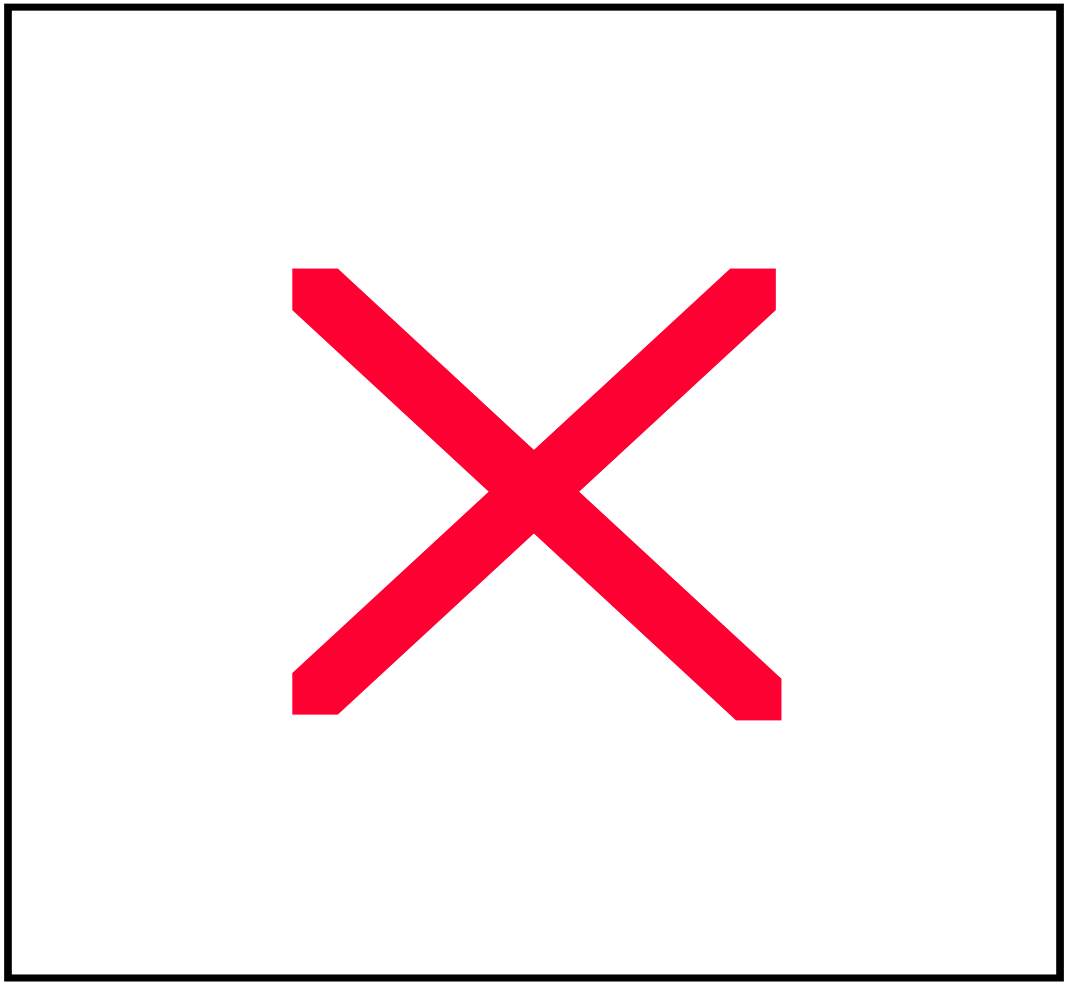
Interference Summary

- **The WindSat Communications Downlink Will Transmit in Either S-band or X-band. The Third Harmonic of the Downlink Could Interfere With the WindSat Payload Receivers. Analysis Shows That the S-band Interference Is Significant. However, a Bandpass Filter Will Suppress the Third Harmonic to Acceptable Levels**

- **Analysis Showed:**
  - **The 3rd Harmonic of the S-band Comms Downlink Introduces a ~0.12K Error (Random and Bias) in 6.8 GHz Band**
  - **A -30db Bandpass Filter Will Suppress the S-band 3rd Harmonic Bias to 0.00012 º K**

- **Study Assumption:**
  - **The Transponder Is Specified to Provide -60dB of Third Harmonic Suppression**

Interference Path

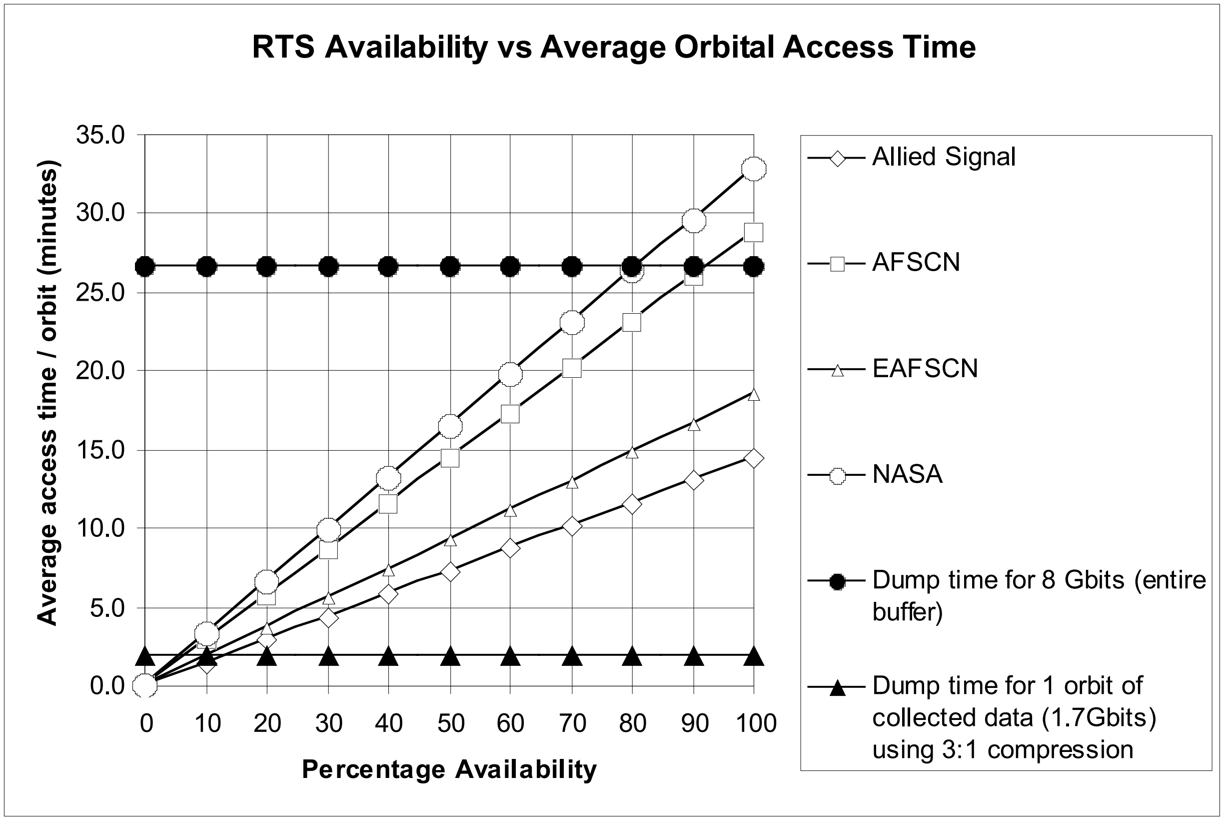


Ground Segment Architecture Candidates

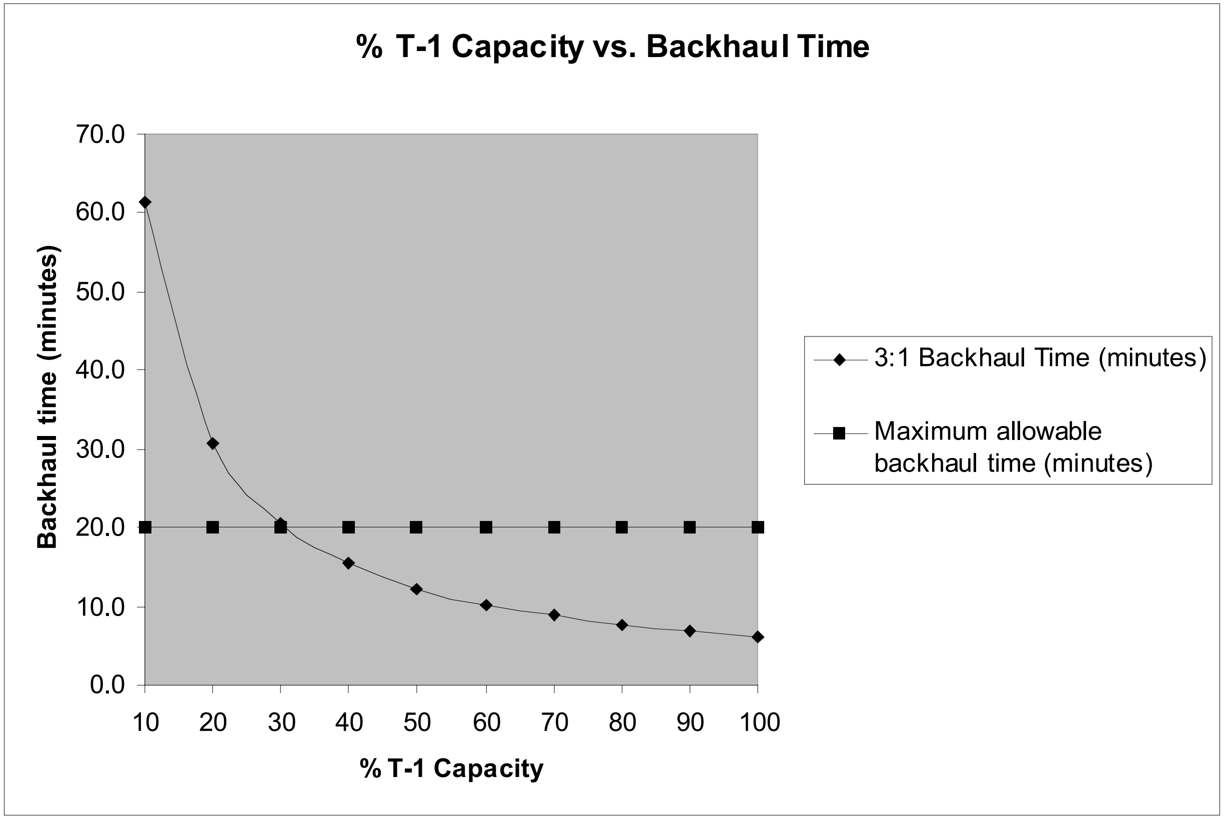
- **Ground Networks That Can Meet WindSat Latency Requirements**
  - AFSCN / EAFSCN*
  - NASA
  - NESDIS (Using AFSCN Assets)
  - Allied Signal
  - Universal Space Network

* Awaiting Facilities / Network Availability Confirmation From Network Providers.

Ground Segment Availability Analysis



Ground Segment Availability Analysis



Tactical Downlink Parameters Delta

Parameter	SSMI	WindSat
RF Downlink	S-Band	S-Band
Data Rate	3.8 kbps	<300kbps
Data Channels	7	22
Word Length	12 bits	14 bits
Interleave on OLS Data Stream	Yes	No
Housekeeping Data	Limited	Extensive
Data Compression	No	3:1
Hot/Cold Calibration Data	Yes	Yes
Payload Modes of Operation	6	2
Channel Sample Rate	Unique	Unique

Ground Segment Architecture
Plan of Action

- Determine Overall Data Compression
- System Error Budget Analysis
- Update ROMs Reflecting Savings Due to Data Compression and Revised WindSat Data Latency Requirements
- Prior to Bus Selection
  - Perform Complete Analysis of Options
  - Participate in Bus Selection Decision
- After Bus Selection
  - Provide a Recommendation on Ground Architecture
  - Develop ICD’s RTS to Satellite, Tactical Term to Satellite

Mission Ops Backup

Backup Slides

S-Band vs. X-Band Interference Analysis
No Bandpass Filtering

Communciations Frequency Band	S		X	
Earth Background Noise Temperature (K)	300		300	
Data Link Fundamental Frequency (GHz)	2.3		8.5	
Data Link EIRB (dB)	4.80		7.00	
Data Link Third Harmonick Level -60 dB (dB)	-55.2		-53.0	
Windsat Sensor Frequency (GHz)	6.8		23.8	
Data Link 3rd Harmonic Interfering Frequency (GHz)	6.9		25.4	
Data Link Interfering Power (dB)	-55.0		-53.0	
Bandpass Filter attenuation at 3rd Harmonic (dB)	**0.0**		**0.0**	
Data Link Comms Antenna Backlobe (dB)	-18.0		-18.0	
Free Space Loss (dB)	44.9		56.2	
Windsat Feed Boresight Gain (dBi)	12.0		12.0	
Windsat Backlobe Level Toward Comms (dB)	-42.0		-42.0	
Windsat Channel Bandwidth (MHz), (dBHz)	125.0	80.97	500.0	86.99
Windsat Receiver Noise Temperature (K), (dBK)	327	25.15	419	26.22
Boltzman's Constant (W/Hz*K), (dBW/Hz*K)	1.380658E-23	-228.60	1.380658E-23	-228.60
Windsat Receiver Interference Rejection (dB)	-9.0		-60.0	
Windsat Sensitivity (dB)	-122.48	5.64344E-13	-115.39	2.89248E-12
Interfering Comms Signal at Windsat LNA, **I** (dB), (W)	-156.90	2.04174E-16	-217.20	1.90546E-22
Windsat Tsys/Inteferer (dB)	34.42		101.81	
Noise, **N** (Overall kTB w/ earth noise included) (dB), (W)	-119.66	1.08209E-12	-113.04	4.96347E-12
I+N (dB), (W)	-119.66	1.08229E-12	-113.04	4.96347E-12
Temperature = (**I**+N)/(kB) (dBK),(K)	27.97	627.1183052	28.57	719
Interference Temperature Bias (K)		**0.11830521**		**0.00000003**

S-Band vs. X-Band Interference Analysis With Bandpass Filtering

Communciations Frequency Band	S		X	
Earth Background Noise Temperature (K)	300		300	
Data Link Fundamental Frequency (GHz)	2.3		8.5	
Data Link EIRB (dB)	4.80		7.00	
Data Link Third Harmonick Level -60 dB (dB)	-55.2		-53.0	
Windsat Sensor Frequency (GHz)	6.8		23.8	
Data Link 3rd Harmonic Interfering Frequency (GHz)	6.9		25.4	
Data Link Interfering Power (dB)	-55.0		-53.0	
Bandpass Filter attenuation at 3rd Harmonic (dB)	**30.0**		**0.0**	
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Windsat Receiver Interference Rejection (dB)	-9.0		-60.0	
Windsat Sensitivity (dB)	-122.48	5.64344E-13	-115.39	2.89248E-12
Interfering Comms Signal at Windsat LNA, **I** (dB), (W)	-186.90	2.04174E-19	-217.20	1.90546E-22
Windsat Tsys/Inteferer (dB)	64.42		101.81	
Noise, **N** (Overall kTB w/ earth noise included) (dB), (W)	-119.66	1.08209E-12	-113.04	4.96347E-12
I+N (dB), (W)	-119.66	1.08209E-12	-113.04	4.96347E-12
Temperature = (I+N)/(kB) (dBK),(K)	27.97	627.0001183	28.57	719
Interference Temperature Bias (K)		**0.00011831**		**0.00000003**

NEDT Summary Budget

- **Minor Noise Figure and Loss Changes Since SRR**

	Random			Ground				
03. NEDT System Level Summary Budgets	**Ant**	**Rx**	Total RSS	Int Beams	EFOV	Requirement	Margin	%Margin
03.01. 37 GHz	0.085	0.385	0.394	20	0.088	0.100	0.012	11.8
03.02. 23.8 GHz	0.060	0.483	0.487	10	0.154	0.200	0.046	23.1
03.03. 18.7 GHz	0.047	0.421	0.424	10	0.134	0.150	0.016	10.7
03.04. 10.7 GHz	0.037	0.409	0.411	10	0.130	0.150	0.020	13.4
03.05. 6.8 GHz	0.053	0.412	0.415	10	0.131	0.200	0.069	34.3

Subsystem Losses as Impacting NEDT:

Subsystem	**6.8**	**10.7**	**18.7**	**23.8**	**37**	**Assumptions**
Antenna						
Horn Loss	0.02	0.03	0.06	0.07	0.11	Linear with Freq
OMT Loss	0.02	0.03	0.06	0.08	0.12	Linear with Freq
Transmission Loss	0.02	0.03	0.05	0.06	0.09	Linear with Freq.
Isolation	0.01	0.01	0.01	0.01	0.01	Isolation= 25
VSWR Mismatch	0.02	0.02	0.02	0.02	0.02	VSWR= 1.15
Subtotal Antenna Pre LNA Loss	0.10	0.13	0.20	0.24	0.35	
Allocated Antenna Loss	0.30	0.30	0.30	0.30	0.40	
Antenna Subsystem Loss Margin in %	68	58	34	20	11	
Receiver						
Pre LNA Losses	0.50	0.15	0.18	0.18	0.18	Isolator +Trans Line
Subtotal Rx Pre LNA Loss	0.50	0.15	0.18	0.18	0.18	
Total Radiometer Pre LNA Losses	0.60	0.28	0.38	0.42	0.53	

Allocated Subsystem Budgets

	Impacted Subsystems							
	Random			**Ground**				
03. NEDT Summary Allocations	**Ant**	**Rx**	Total RSS	Int Beams	EFOV	Requirement	Margin	%Margin
03.01. 37 GHz	0.060	0.417	0.421	20	0.094	0.100	0.006	6
03.02. 23.8 GHz	0.060	0.602	0.605	10	0.191	0.200	0.009	4
03.03. 18.7 GHz	0.060	0.444	0.448	10	0.142	0.150	0.008	6
03.04. 10.7 GHz	0.060	0.444	0.448	10	0.142	0.150	0.008	6
03.05. 6.8 GHz	0.060	0.602	0.605	10	0.191	0.200	0.009	4

Basis of Allocation is a Scene Temperature of 250 K

BER of Data Handling, Slip Rings, and Communications Subsystems is Insignificant

Payload Receiver Subsystem

J. Xavier

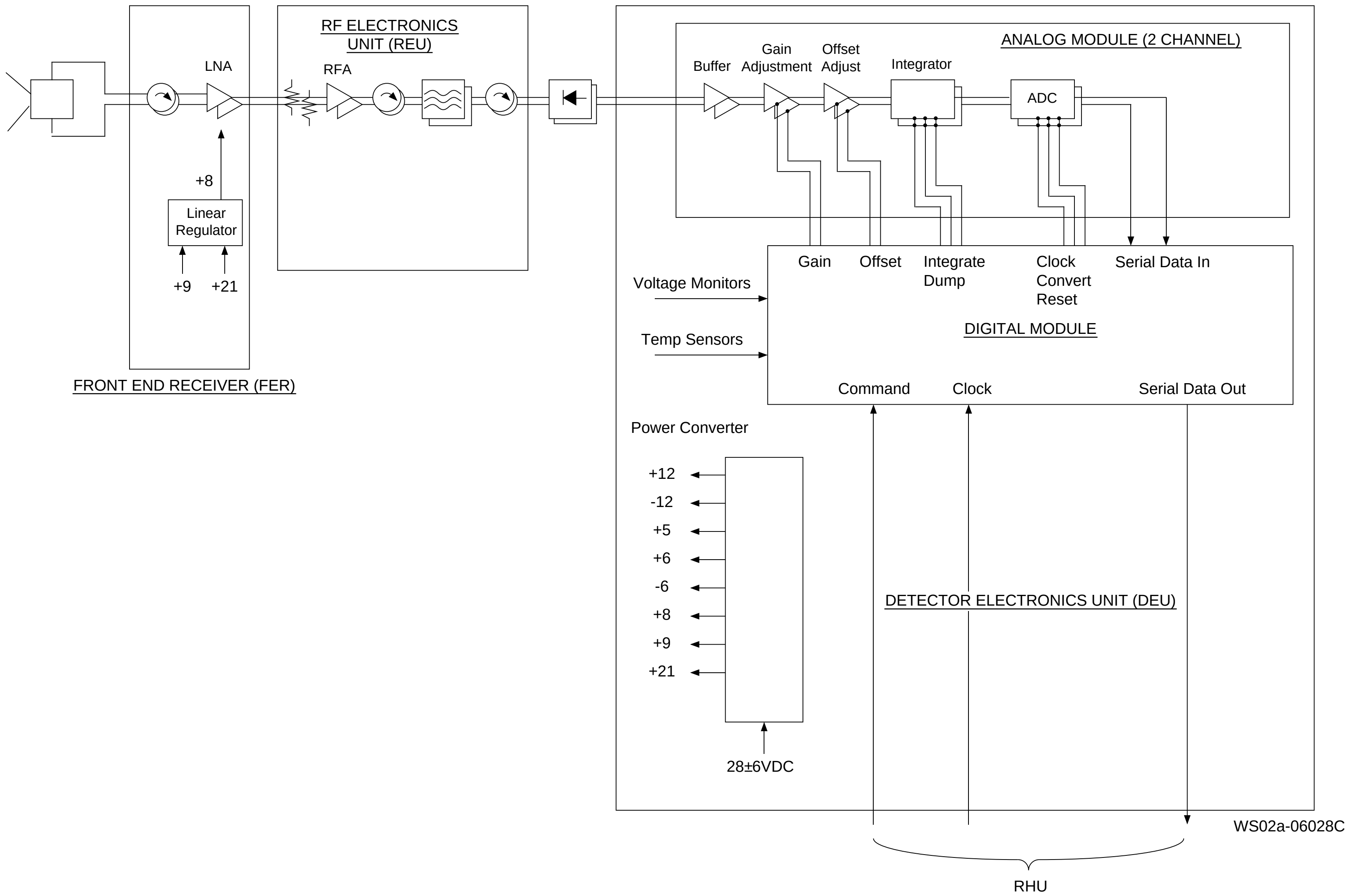
Payload Receiver Subsystem

Requirements Summary

Payload Receiver Subsystem Functional Description

- Measure Scene And Calibration Load Brightness Temperature For Eleven Polarization Pairs Covering Five Frequency Bands.
- Provide Required Radiometric Sensitivity For Each Measurement.
- Provide Gain And DC Offset Adjustment Capability.
- Output One Serial Data Stream For Each Frequency Band
- Collect and Report Receiver Physical Temperature Data
- Generate DC Power From S/C Bus Power
- Accept Timing Signals From Rotating Data Handling Unit To Synchronize Radiometer Sampling To Antenna Rotation At The Point That Maximizes Calibration Repeatability.

2 Channel Receiver Architecture



Payload Receiver Subsystem
Allocated Requirements Summary

Requirement Description	Required Performance	Predicted Performance	Margin
Receiver NEDT			
6.8 GHz	.602 K	.415 K	.187 K
10.7 GHz	.444 K	.413 K	.031 K
18.7 GHz	.444 K	.426 K	.018 K
23.8 GHz	.602 K	.488 K	.114 K
37.0 GHZ	.417 K	.396 K	.021 K
Frequency Channels	6.8 GHz	6.8 GHz	N/A
	10.7 GHz	10.7 GHz	N/A
	18.7 GHz	18.7 GHz	N/A
	23.8 GHz	23.8 GHz	N/A
	37 GHZ	37 GHZ	N/A
Channel Noise Bandwidth			
6.8 GHz	125 MHz	125 MHz	N/A
10.7 GHz	200 MHz	200 MHz	N/A
18.7 GHz	500 MHz	500 MHz	N/A
23.8 GHz	500 MHz	500 MHz	N/A
37 GHZ	2000 MHz	2000 MHz	N/A
Receiver Integration Time			
6.8 GHz	5.45 msec		
10.7 GHz	3.46 msec		
18.7 GHz	1.98 msec	Compliant/Adjustable VIA DHU Command	N/A
23.8 GHz	1.56 msec		
37 GHZ	1.00 msec		
Input Signal Levels			
Calibration	3 K to 330 K	N/A	N/A
Operating	3 K to 250 K	N/A	N/A
Non-Destructive	+10 dBm	+15 dBm	5 dB

Payload Receiver Subsystem
Allocated Requirements Summary (Cont.)

Requirement Description	Required Performance	Predicted Performance	Margin
Scan Synchronization	Synchronize Start of Data Collection to Maximize Calibration Repeatability	Scan Timing Adjustable to 1 μsec Granularity	N/A
Cross-Polarization Isolation	55 dB, Minimum	65 dB	10 dB

Payload Receiver Requirements
Derived Requirements Summary

Requirement Description	Required Performance	Predicted Performance	Margin
Noise Figure			
6.8 GHz	2.60 dB	1.14 dB	1.36 dB
10.7 GHz	1.50 dB	1.14 dB	0.36 dB
18.7 GHz	2.20 dB	1.94 dB	0.26 dB
23.8 GHz	2.95 dB	2.03 dB	0.92 dB
37 GHZ	3.37 dB	2.97 dB	0.40 dB
Quantization	14 effective bits LSB weighting < 15% of Required Delta T	14 effective bits LSB weighting = 13.2 ºK	0 bits 1.8%
Input Return Loss	19 dB, minimum	23 dB	4 dB

Payload Receiver Subsystem Trade Studies

- Detector Type: Schottky vs. Tunnel Diode Detectors
  - Tunnel Diodes Have Superior Close-In Noise Performance; Better
    - System Noise Performance With Low Post-Detection Bandwidths
  - Tunnel Diodes Have Lower Output Resistance; Allow for Low
    - Resistance Audio Back End, Improved Post-Detection Noise
  - Trade Study Complete Tunnel Diodes Preferred Detector Type

- Simple Polarization Pair Receiver vs. Polarization Combining Receiver
  - Polarization Combining Receiver Reduces Size, Weight, and Power of Receiver Subsystem
  - Simple Polarization Pair Receiver Reduces Calibration Complexity,
    - Reduces Cross-Polarization Coupling Paths
  - Simple Polarization Pair Receiver Selected

Payload Receiver Subsystem Trade Studies (Cont.)

- **Front- End RFI Filtering: Size, Weight, and Loss vs. Sensor Availability**
  - **Studies Found No Emitter That Can Present A Damaging Signal To The Sensor**
  - **Studies Show That Sensor Availability Will Be High Over Open Oceans**
  - **Sensor Sensitivity Will Be Reduced Periodically Over Shipping Lanes And Non-Ocean Areas**
  - **Front- End RFI Filtering Will Not Be Included In WindSat Design**

- **Receiver Power Architecture - Centralized vs. Distributed**
  - **Distributed Power Selected To Improve EMC/EMI Performance**

Payload Receiver Subsystem
Trade Studies (cont.)

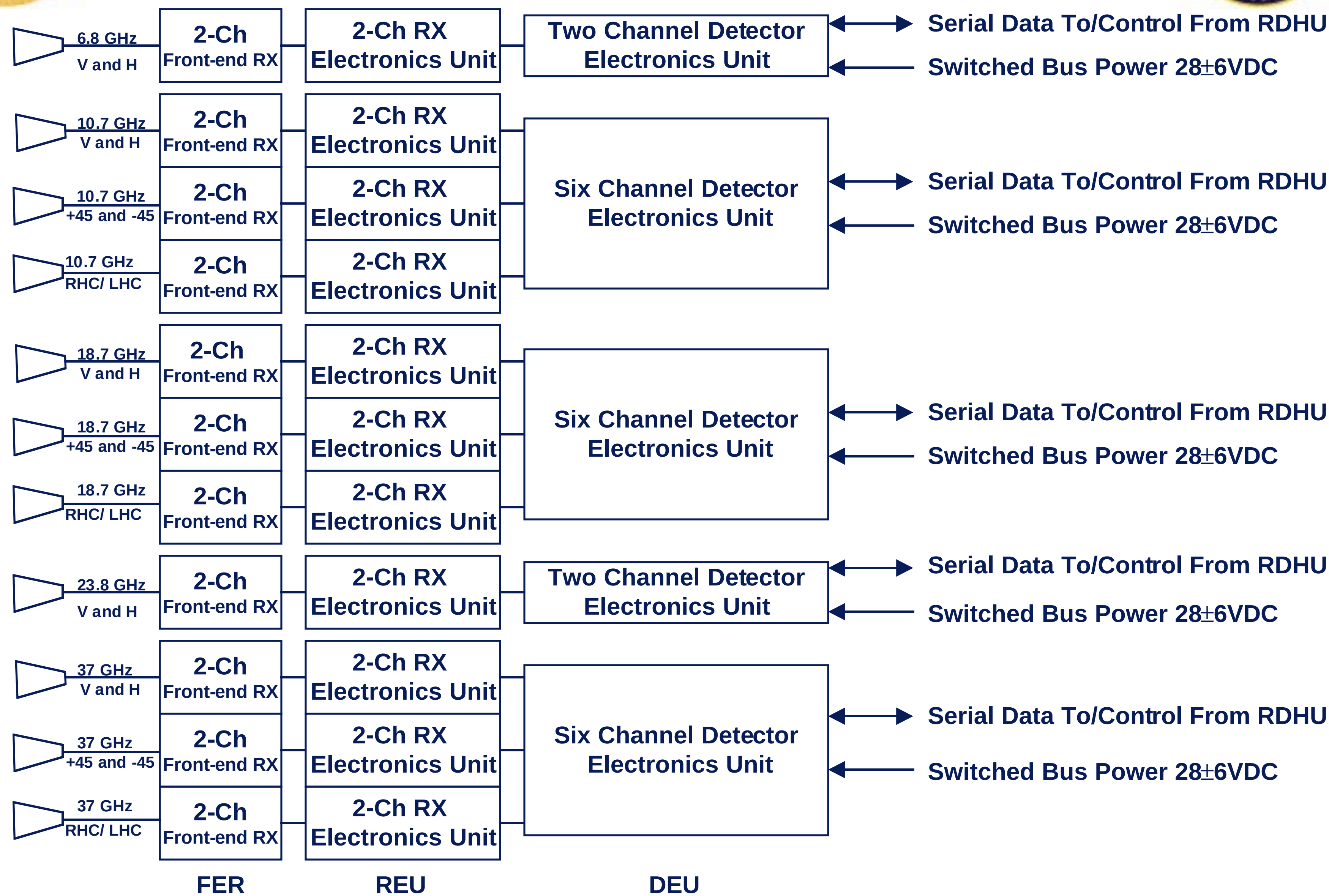
- **Receiver/DHS Interface Definition**
  - **Location Of Control Signal Generation In DEU vs In DHS**
    - **Selected DEU To Simplify Physical Interface**
  - **Formatting Schemes**
    - **Selected SDLC Due To COTS Interface HW Availability And Ease Of Implementation**

- **Analog VS Digital Integration**
  - **Selected Analog To Reduce Required Sample Clock Rate And Simplify Data Processing**
  - **Analog Approach Is Design Heritage**

Payload Receiver Subsystem

Electrical Design

Payload Receiver Subsystem Functional Block Diagram



Receiver EMC/EMI Design Approach

- <u>Objective</u>: Mitigate Effects Of Power Converter Ripple, Digital Switching Transients, BAPTA And MWA Motor EMI, And Communication Subsystem Interference
- Connectorized FER/DEU Modules For Maximum Shielding
- Compartmented DEU To Isolate Power And Digital Functions From Audio Processor
- Design Requires Output Filter On Comm Transmitters To Suppress Harmonics
- Continuous Shield Cabling, MIL-C-38999, Series 4 Circular Connectors With EMI Backshells
- Cables And Connectors Segregated According To Signal Frequency, Rise Time, And Fall Time
- Audio Processor Designed For Maximum Power Converter Ripple Rejection

Payload Receiver Subsystem

Electrical Design Analyses

Payload Receiver Subsystem Radiometric Sensitivity Analysis

Channel	#	1	2	3	4	5	
Center Frequency	GHz	6.8	10.7	18.7	23.8	37	**Notes**
Max Calibration Temp	deg K	330	330	330	330	330	
Max Operating Ant. Temp	deg K	250	250	250	250	250	
Min Operating Ant. Temp	deg K	3	3	3	3	3	
RFE Loss	dB	0.5	0.15	0.18	0.18	0.18	
LNA Noise Figure	dB	0.6	0.95	1.7	1.8	2.7	
LNA Gain	dB	25	30	25	25	28	
RF Attenuator	dB	2	7	5	4	10	
RF Amp N.F.	dB	4	4	4	4	4	
Noise Figure	dB	1.14	1.14	1.94	2.03	2.97	
Integration Time	ms	5.45	3.46	1.98	1.56	1.00	
Max Cal System Temp	deg. K	417	417	494	503	614	
Max Op System Temp	deg. K	337	337	414	423	534	
Min Op System Temp	deg. K	90	90	167	176	287	
Pre-Detection Bandwidth	MHz	125	200	500	500	2000	
Post-Detection Bandwidth	kHz	3	5	7	7	14	
Delta T Receiver	deg. K	0.408	0.405	0.416	0.478	0.378	To in deg K= 290
Detector Sensitivity	mv/milliwatt	900	800	400	400	300	Tamax in deg K= 250
Min Detector Input Level	dBm	-35.65	-35.39	-32.44	-31.82	-28.60	Tamin in deg K= 3
Max Detector Input Level (Op)	dBm	-25.41	-25.36	-24.19	-23.70	-21.71	
Max Detector Input Level (Cal)	dBm	-24.48	-24.44	-23.43	-22.95	-21.11	
Sensitivity Temp Variation	dB/deg C	0.006	0.006	0.006	0.006	0.006	±0.5 dB over -55 to +125 °C
Temp. Drift	deg C/sec	0.005	0.005	0.005	0.005	0.005	
Delta K/K (temperature)	unitless	0.00001	0.00001	0.00001	0.00001	0.00001	
Video Noise	deg K	0.030	0.030	0.030	0.030	0.030	-20 dBc Noise Contribution
Delta T Video vs. Temp	deg. K	0.004	0.004	0.005	0.005	0.007	
Min ADC Input Voltage	V	0.35	0.37	0.57	0.59	0.93	Min Input Temp at Min Gain
Max ADC Input Voltage (Ops)	V	3.66	3.69	3.83	3.82	4.53	Max Operational Input Temp at Max Gain
Max ADC Input Voltage (Cal)	V	4.53	4.56	4.57	4.54	5.21	Max Calibration Input Temp at Max Gain
# of raw ADC Bits	bits	16.00	16.00	16.00	16.00	16.00	
Raw ADC Resolution	deg K/count	0.004	0.004	0.004	0.004	0.004	
ADC Non-linearities	LSBs	2.00	2.00	2.00	2.00	2.00	Manufacturer Specification
Delta T ADC Non-Linearities	deg K	0.008	0.008	0.008	0.008	0.008	
# of effective ADC bits	bits	14.00	14.00	14.00	14.00	14.00	
Effective A/D Resolution	deg K/count	0.015	0.015	0.015	0.015	0.015	
Quantization Noise	deg K	0.008	0.008	0.008	0.008	0.008	
RF Gain	dB	64.7	62.8	59.1	59.5	54.5	ALL RF Circuitry up to Detector
Long Term Gain Variation	+/- dB	2.25	2.15	2.15	2.15	2.1	0 to +40 C
Gain vs Temp	dB/deg C	0.09	0.09	0.09	0.09	0.09	Gain Var .09 dB/°C
Temp. Drift	deg C/sec	0.005	0.005	0.005	0.005	0.005	
Delta G	unitless	0.00021	0.00021	0.00021	0.00021	0.00021	
Cal Period Delta T (Delta G)	deg K	0.071	0.071	0.087	0.089	0.112	
Audio Gain	dB	63.0	64.0	68.0	67.0	67.0	per stage EOL = .4% (.04dB)
Min Detector Output Level	mV	0.2	0.2	0.228	0.263	0.414	for 3 year mission
Max Detector Output Level (Op)	mV	2.6	2.3	1.523	1.706	2.023	Temp Variation 300ppm/ C/stage
Max Detector Output Level (Cal)	mV	3.2	2.9	1.818	2.029	2.326	
Gain vs Temp	dB/deg C	0.0066	0.0067	0.0071	0.0070	0.0070	Equiv = .0026 dB/ C/stage
Temp. Drift	deg C/sec	0.005	0.005	0.005	0.005	0.005	Audio Gain 25 dB/stage
Delta G (temperature)	unitless	0.000008	0.000008	0.000008	0.000008	0.000008	
Delta T (Delta G)	deg K	0.003	0.003	0.003	0.003	0.004	RPM= 29.57
Receiver NEDT	deg K	0.415	0.413	0.426	0.488	0.396	PERIOD (sec) 2.03
Required NEDeltaT	deg K	0.602	0.444	0.444	0.602	0.417	**RECEIVER ONLY!**
Margin	deg K	0.187	0.031	0.018	0.114	0.021	

Payload Receiver Subsystem
RF Design Analyses

- **Frequency Channel Amplitude Performance**
- **Detector Linearity Performance**
- **Channel Noise Bandwidth**

Payload Receiver Subsystem
6.8 GHz Amplitude Performance

Reference Designation	Input	Channel Microwave	MITEQ	Omni Spectra	MITEQ	M/A-COM	K&L	M/A-COM
Description	Source	Isolator/Transition	LNA	Attenuator	Amplifier	Isolator	BPF	Isolator
Part Number	OMT	GC3XX		2082-6041-02		M2E-7200	6C50-6800/T125-0/(	M2E-7200
Device Parameters								
Nominal Gain (dB)	N/A	-0.40	25.00	-2.00	44.00	-0.20	-1.50	-0.20
Gain Variation over Temperature (dB)	0.00	0.20	1.00	0.20	2.00	0.30	0.50	0.30
Amplifier 1 dB Compression Point (dBm)	N/A	N/A	0.00	N/A	0.00	N/A	N/A	N/A
1 dB Compression Point Variation over Temperature	N/A	N/A	2.00	N/A	2.00	N/A	N/A	N/A
Amplifier Saturated Output Power (dBm)	N/A	N/A	4.00	N/A	4.00	N/A	N/A	N/A
Saturated Output Power Over Temperature (dB)	N/A	N/A	2.00	N/A	2.00	N/A	N/A	N/A
Amplifier Noise Figure (dB)	N/A	N/A	0.60	N/A	4.00	N/A	N/A	N/A
Power Level Analysis								
Nominal Device Output Level (dBm)	-94.2	-94.6	-69.6	-71.6	-27.6	-27.8	-29.3	-29.5
Minimum Device Output Level (dBm)	-97.7	-98.2	-73.7	-75.8	-32.8	-33.2	-34.9	-35.3
Maximum Device Output Level (dBm)	-92.3	-92.6	-67.1	-69.0	-24.0	-24.0	-25.3	-25.3

Payload Receiver Subsystem
10.7 GHz Amplitude Performance

Reference Designation	Input	EMS	MITEQ	Omni Spectra	MITEQ	M/A-COM	K&L	M/A-COM
Description	Source	Isolator	LNA	Attenuator	Amplifier	Isolator	BPF	Isolator
Part Number	OMT	415A-ST	JSWS3-10601080-95-0P-40T	2082-6041-07	JS4-10601080-40-0P	M2E-10750	6C52-10700/T200-0/0	M2E-10750
Device Parameters								
Nominal Gain (dB)	N/A	-0.15	30.00	-7.00	42.00	-0.30	-1.50	-0.30
Gain Variation over Temperature (dB)	0.00	0.20	1.00	0.20	2.00	0.20	0.50	0.20
Amplifier 1 dB Compression Point (dBm)	N/A	N/A	10.00	N/A	0.00	N/A	N/A	N/A
1 dB Compression Point Variation over Temperature	N/A	N/A	2.00	N/A	2.00	N/A	N/A	N/A
Amplifier Saturated Output Power (dBm)	N/A	N/A	14.00	N/A	4.00	N/A	N/A	N/A
Saturated Output Power Over Temperature (dB)	N/A	N/A	2.00	N/A	2.00	N/A	N/A	N/A
Amplifier Noise Figure (dB)	N/A	N/A	0.95	N/A	4.00	N/A	N/A	N/A
Power Level Analysis								
Nominal Device Output Level (dBm)	-91.8	-91.9	-61.9	-68.9	-26.9	-27.2	-28.7	-29.0
Minimum Device Output Level (dBm)	-94.9	-95.2	-65.7	-72.8	-31.8	-32.2	-33.9	-34.3
Maximum Device Output Level (dBm)	-90.0	-90.0	-59.5	-66.4	-23.4	-23.6	-24.9	-25.1

Payload Receiver Subsystem
18.7 GHz Amplitude Performance

Reference Designation	Input	EMS	MITEQ	Omni Spectra		TRAK	K&L	TRAK
Description	Source	Isolator	LNA	Attenuator	Amplifier	Isolator	BPF	Isolator
Part Number	OMT	417A-ST		2082-6041-03		20A8021	6FV10-18700/T500-K/K	20A8021
Device Parameters								
Nominal Gain (dB)	N/A	-0.20	25.00	-3.00	40.00	-0.60	-1.50	-0.60
Gain Variation over Temperature (dB)	0.00	0.20	1.00	0.20	2.00	0.20	0.50	0.20
Amplifier 1 dB Compression Point (dBm)	N/A	N/A	0.00	N/A	0.00	N/A	N/A	N/A
1 dB Compression Point Variation over Temperature (dB)	N/A	N/A	2.00	N/A	2.00	N/A	N/A	N/A
Amplifier Saturated Output Power (dBm)	N/A	N/A	4.00	N/A	4.00	N/A	N/A	N/A
Saturated Output Power Over Temperature (dB)	N/A	N/A	2.00	N/A	2.00	N/A	N/A	N/A
Amplifier Noise Figure (dB)	N/A	N/A	1.70	N/A	4.00	N/A	N/A	N/A
Power Level Analysis								
Nominal Device Output Level (dBm)	-86.5	-86.7	-61.7	-64.7	-24.7	-25.3	-26.8	-27.4
Minimum Device Output Level (dBm)	-88.6	-88.9	-64.4	-67.5	-28.5	-29.2	-31.0	-31.7
Maximum Device Output Level (dBm)	-85.1	-85.2	-59.7	-62.6	-21.6	-22.1	-23.4	-23.9

Payload Receiver Subsystem
23.8 GHz Amplitude Performance

Reference Designation	Input	EMS	MITEQ	Weinschel	MITEQ	TRAK	K&L	TRAK
Description	Source	Isolator	LNA	Attenuator	Amplifier	Isolator	BPF	Isolator
Part Number	OMT	417A-ST		56-02		60A8101	6FV10-23800/T500-K/K	60A8101
Device Parameters								
Nominal Gain (dB)	N/A	-0.20	25.00	-2.00	40.00	-0.90	-1.50	-0.90
Gain Variation over Temperature (dB)	0.00	0.20	1.00	0.20	2.00	0.20	0.50	0.20
Amplifier 1 dB Compression Point (dBm)	N/A	N/A	0.00	N/A	0.00	N/A	N/A	N/A
1 dB Compression Point Variation over Temperature (dB)	N/A	N/A	2.00	N/A	2.00	N/A	N/A	N/A
Amplifier Saturated Output Power (dBm)	N/A	N/A	4.00	N/A	4.00	N/A	N/A	N/A
Saturated Output Power Over Temperature (dB)	N/A	N/A	2.00	N/A	2.00	N/A	N/A	N/A
Amplifier Noise Figure (dB)	N/A	N/A	1.80	N/A	4.00	N/A	N/A	N/A
Power Level Analysis								
Nominal Device Output Level (dBm)	-86.4	-86.6	-61.6	-63.6	-23.6	-24.5	-26.0	-26.9
Minimum Device Output Level (dBm)	-88.4	-88.7	-64.2	-66.3	-27.3	-28.3	-30.1	-31.1
Maximum Device Output Level (dBm)	-85.0	-85.1	-59.6	-61.5	-20.5	-21.3	-22.6	-23.4

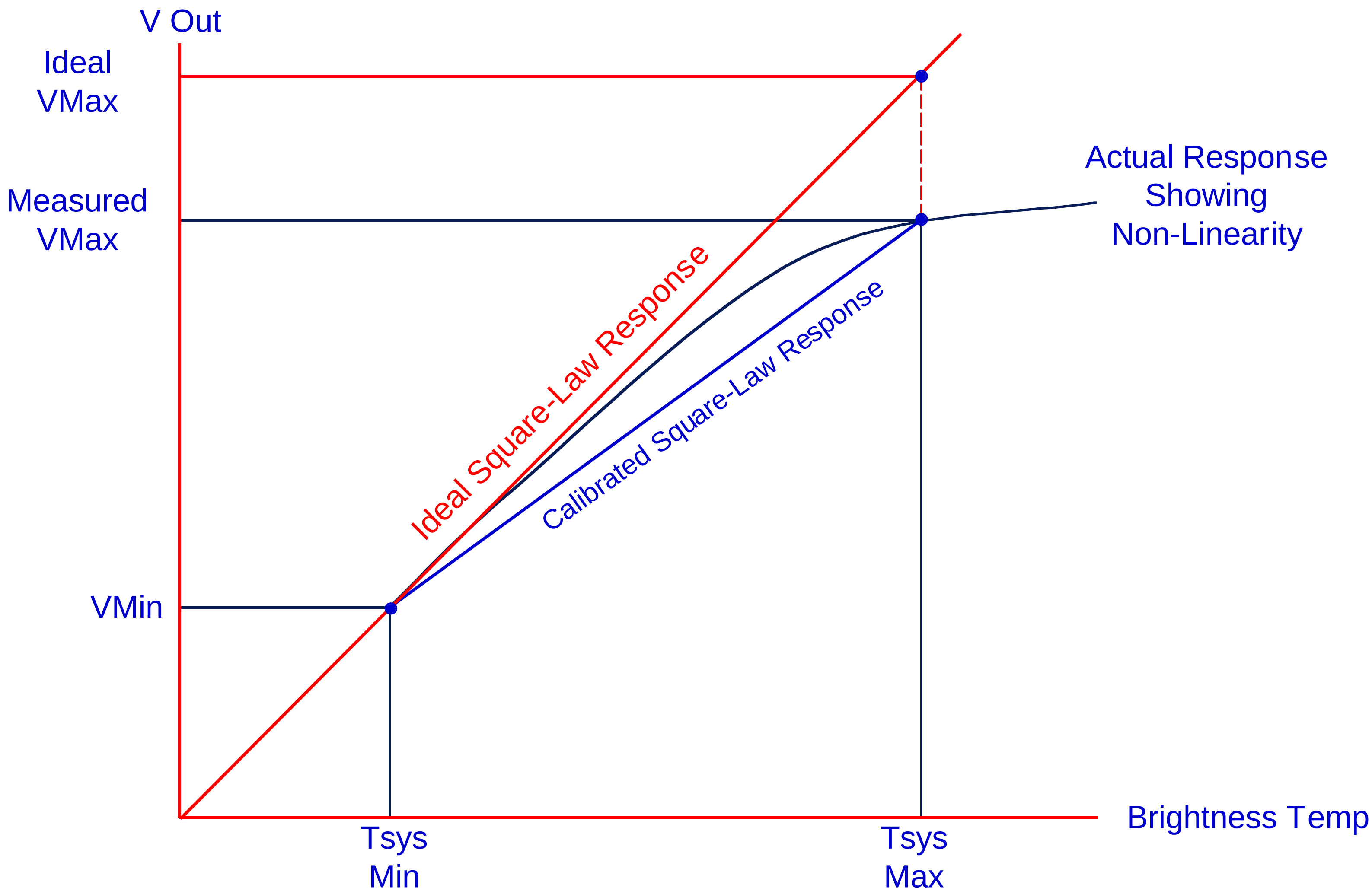
Payload Receiver Subsystem
37 GHz Amplitude Performance

Reference Designation	Input	EMS	MITEQ	Weinschel	MITEQ	MDC	K&L	MDC
Description	Source	Isolator	LNA	Attenuator	Amplifier	Isolator	BPF	Isolator
Part Number	OMT	418A-ST	JSWK4-36003800-28-0P-40T	Model 54		58028-445	6FVSP-3700/T2000-K/K	58028-445
Device Parameters								
Nominal Gain (dB)	N/A	-0.18	28.00	-4.00	35.00	-0.40	-1.50	-0.40
Gain Variation over Temperature (dB)	0.00	0.10	1.00	0.20	2.00	0.20	0.50	0.20
Amplifier 1 dB Compression Point (dBm)	N/A	N/A	9.20	N/A	0.00	N/A	N/A	N/A
1 dB Compression Point Variation over Temperature (dB)	N/A	N/A	2.00	N/A	2.00	N/A	N/A	N/A
Amplifier Saturated Output Power (dBm)	N/A	N/A	14.00	N/A	4.00	N/A	N/A	N/A
Saturated Output Power Over Temperature (dB)	N/A	N/A	2.00	N/A	2.00	N/A	N/A	N/A
Amplifier Noise Figure (dB)	N/A	N/A	2.70	N/A	4.00	N/A	N/A	N/A
Power Level Analysis								
Nominal Device Output Level (dBm)	-79.1	-79.3	-51.3	-55.3	-20.3	-20.7	-22.2	-22.6
Minimum Device Output Level (dBm)	-80.5	-80.7	-53.2	-57.3	-23.3	-23.8	-25.6	-26.1
Maximum Device Output Level (dBm)	-78.0	-78.2	-49.7	-53.6	-17.6	-17.9	-19.1	-19.4

Detector Linearity Characterization

- Receiver Non-linearity Errors In Radiometer Measurements Are A Function Of Scene Temperature. Therefore Cannot Be Corrected By Two Point Calibration.
- Non-linearities Are Due To Amplifiers And Detectors.
- Intercept Point Specifications Mitigate Amplifier Non-Linearity Errors Over The WindSat Operating Dynamic Range.
- Receiver Analysis Showed .1% Detector Linearity Required For 0.5K Channel Bias Error Limit.
- Detector Linearity Characterization Performed As Part Of Breadboard Test Effort.

Effect Of Detector Non-Linearity On Two-Point Calibration



Payload Receiver Subsystem
Channel Noise Bandwidth Performance

- **WindSat Radiometric Sensitivity Is A Function Of The Noise Bandwidth Of The Receivers.**
- **Filter Type Is Specified As 6-Section, .05 dB Ripple Chebyshev.**
- **The 6-Section Filter Of This Type Has A Noise Bandwidth Equal To The 3dB Bandwidth.**

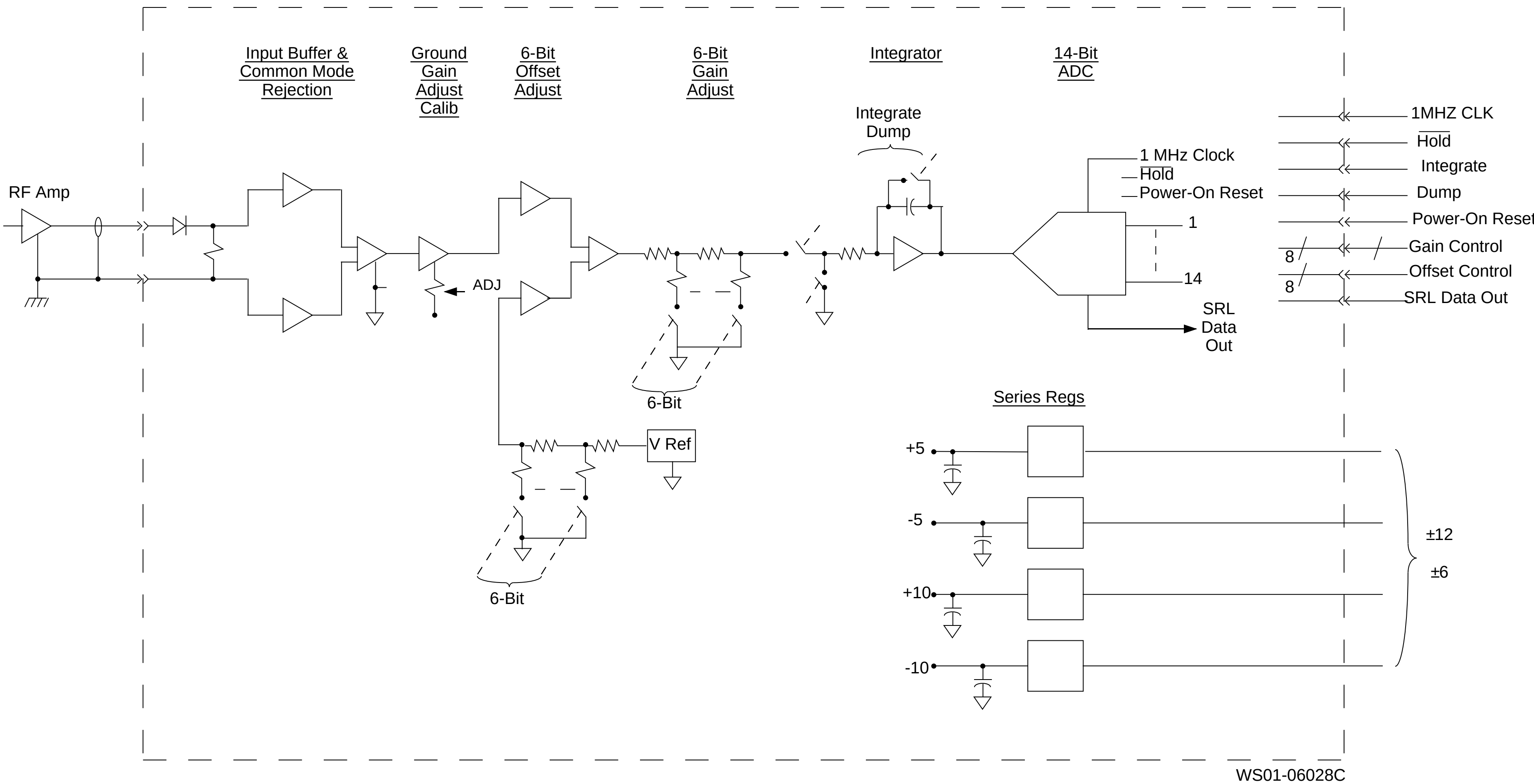
Payload Receiver Subsystem
Detector Electronics Unit Design Analyses

- Block Diagram
- ADC Operating Range
- Common Mode Performance
- Gain Adjustment Performance
- DC Offset Performance
- Gain And Offset Adjustment
- Timing Sequence
- Input Dynamic Range Performance
- 16-Bit ADC Test Results
- Noise Analysis

DEU Requirements
Derived Requirements Summary

Requirement Description	Required Performance	Predicted Performance	Margin
Audio Input Dynamic Range			
6.8 GHz	0.3 to 3.4 mV	0 to 3.5 mV	0.40 mV
10.7 GHz	0.3 to 3.1 mV	0 to 3.14 mV	0.34 mV
18.7 GHz	0.3 to 1.9 mV	0 to 2.06 mV	0.46 mV
23.8 GHz	0.3 to 2.2 mV	0 to 2.32 mV	0.42 mV
37 GHZ	0.5 to 2.48 mV	0 to 2.48 mV	0.50 mV
ADC Input Dynamic Range			
6.8 GHz	4.5 V Max Input Level 0 V Min Input Level In Each Frequency Band Over Operating Temperature Range	0.2 to 4.37 mV	130 mV
10.7 GHz		0.2 to 4.39 mV	110 mV
18.7 GHz		0.1 to 4.18 mV	320 mV
23.8 GHz		0 to 4.14 mV	360 mV
37 GHZ		0 to 4.49 mV	10 mV
ADC Quantization Step Size			
6.8 GHz	0.090 K	0.029 K	0.061 K
10.7 GHz	0.066 K	0.031 K	0.035 K
18.7 GHz	0.066 K	0.058 K	0.008 K
23.8 GHz	0.090 K	0.052 K	0.038 K
37 GHZ	0.063 K	0.055 K	0.008 K
Gain And DC Offset Adjustment Granularity	0.5 dB Max Step Size	0.27 dB Max Step Size	0.23 dB

Breadboard Detector Electronics Unit
Breadboard Block Diagram



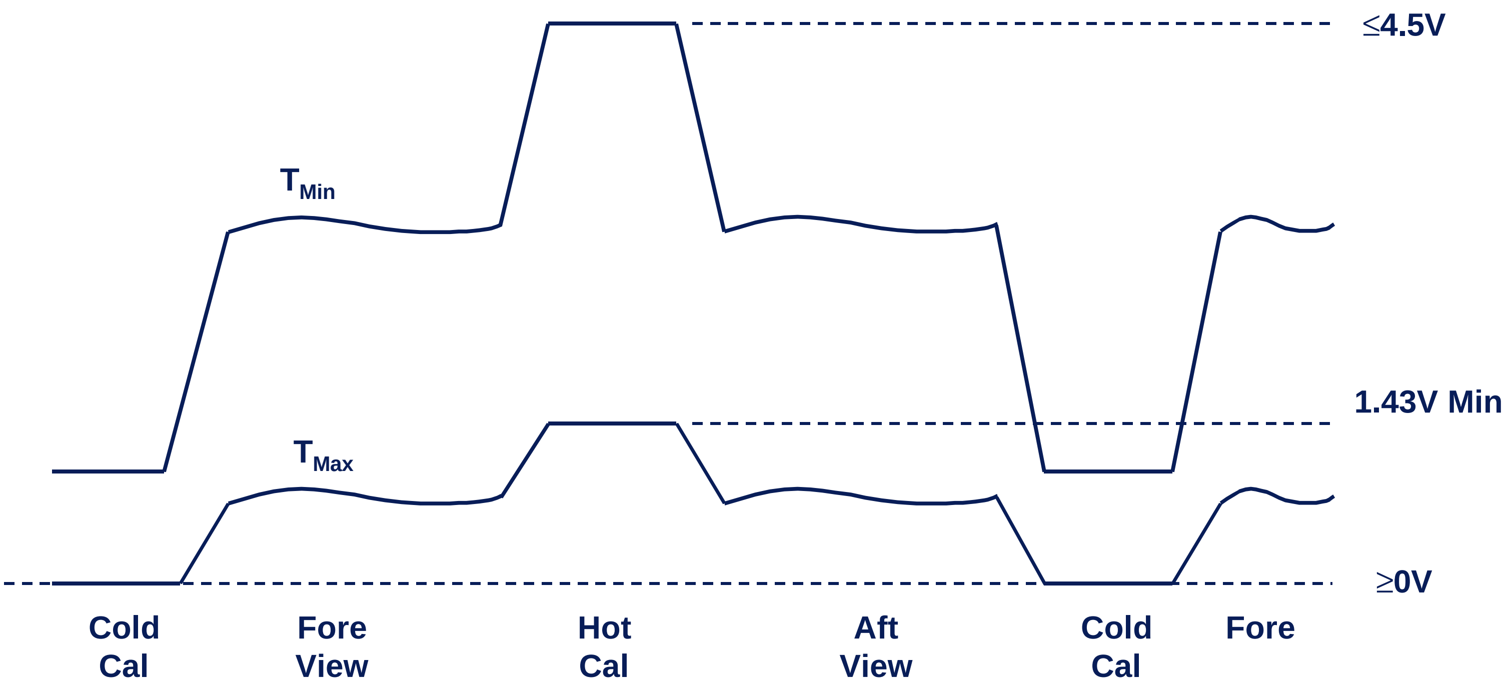
ADC Operating Range Requirements Derivation

- WindSat ADC Is Required To Provide Max Granularity Of 15% Of ΔT Requirement In Each Frequency Band
- For 37 GHz Channel - ΔT Requirement Is .417K Resulting In A Granularity Requirement Of .063K
- WindSat ADC Is A 14 Effective Bit Device Which Digitizes System Brightness Temperature In The Range Of 3K (Cold Calibration) To 330K (Hot Calibration). The Device Operates Over A Linear Input Voltage Range Of 0 To 4.5V
- Minimum Input Voltage Range Is

$$\text{Input Range} = \frac{(330\text{K} - 3\text{K})}{.063\text{K}/_{\text{Count}}} \bullet \frac{4.5 \text{ Volts}}{2^{14} \text{ Counts}} = 1.43\text{V}$$

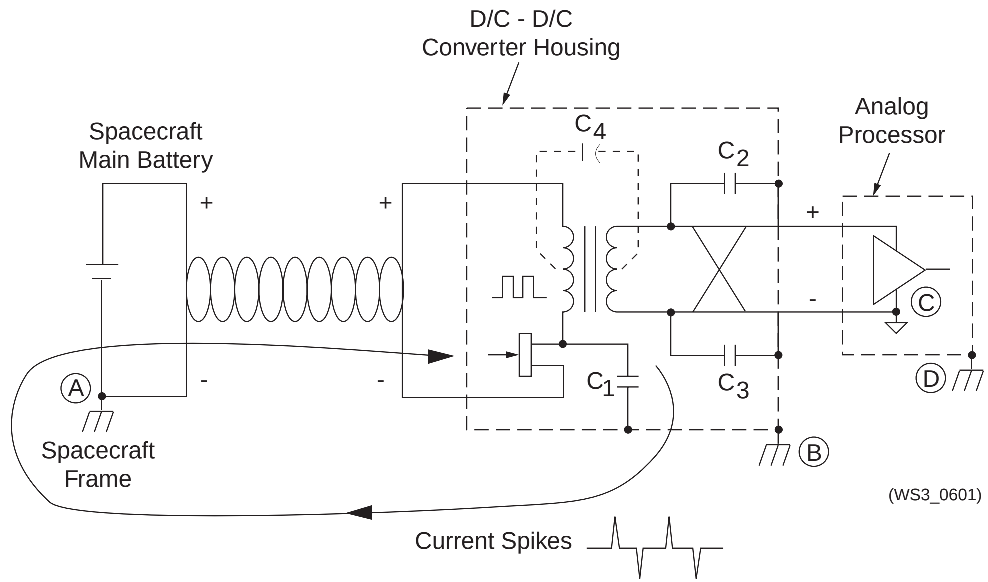
ADC Operating Range Requirements

- Over Operating Temperature Range Of Receiver Subsystem The Signal At ADC Input:
  - $V_{max} = 4.5V$
  - $V_{min} = 0V$
  - $V_{MinHotCal} - V_{MinColdCal} \geq 1.43V$

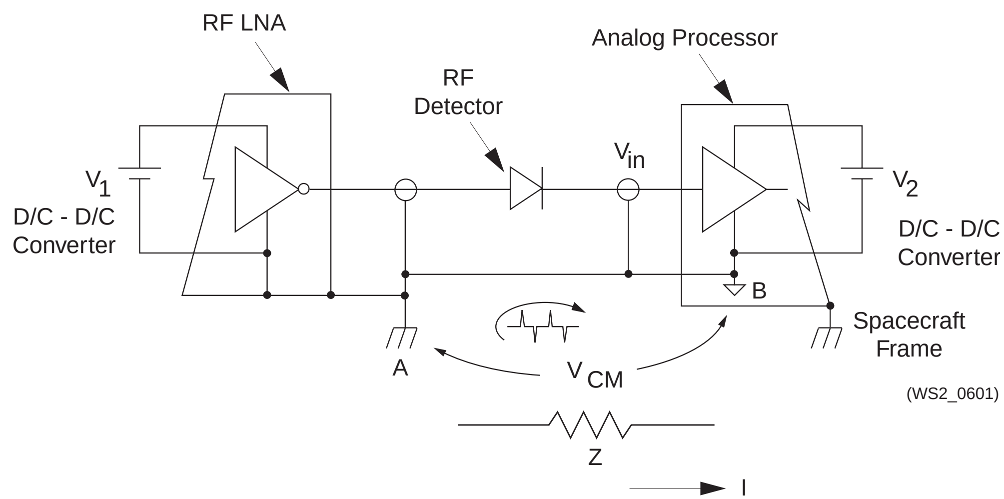


Detector Electronics Unit
Common Mode Noise

Typical Sources Of Common Mode Noise



Effects Of Common Mode Noise



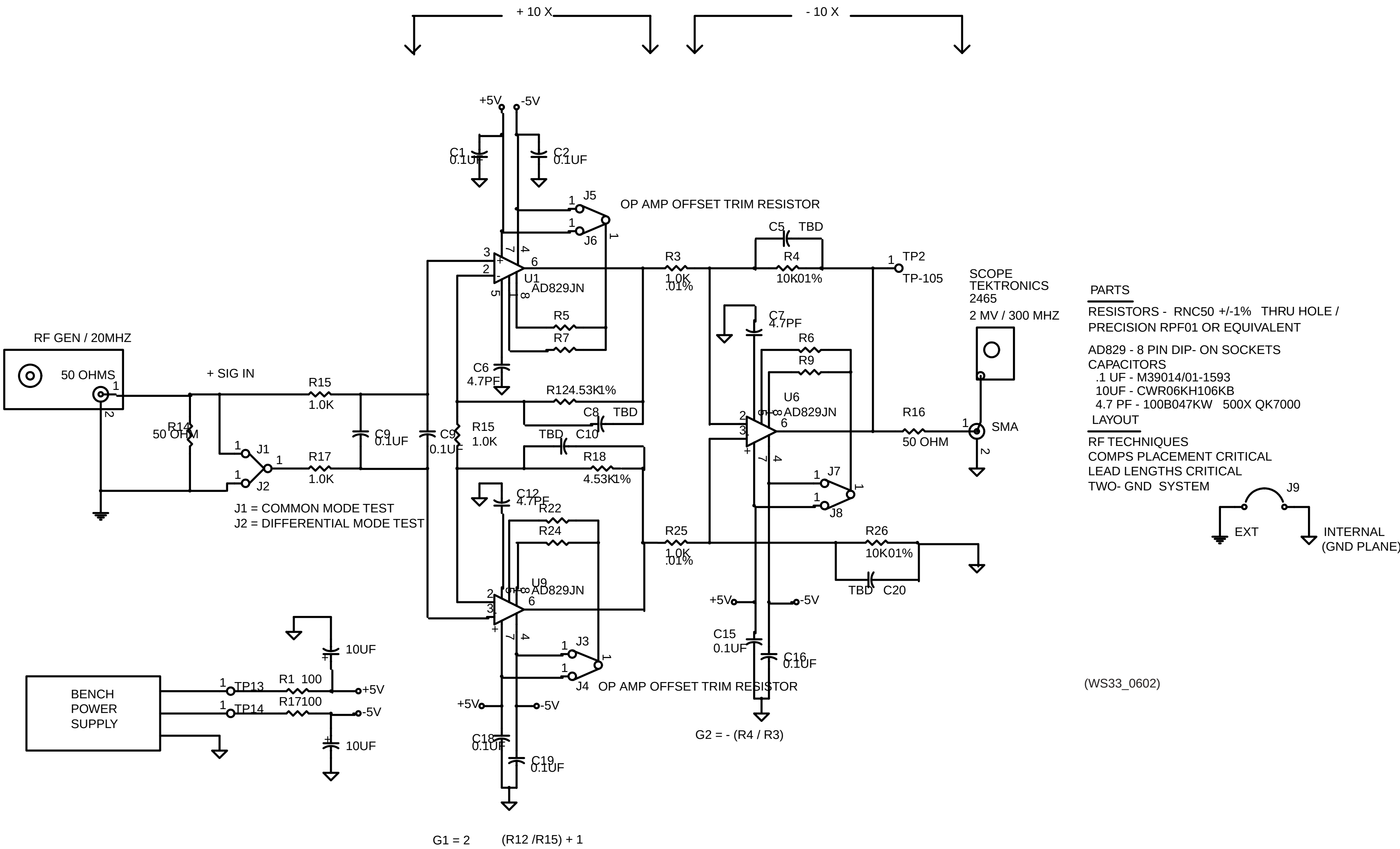
Detector Electronics Unit
Common Mode Rejection Performance

- **Breadboard Test Set-Up As Per Schematic**
- **Signal Applied At Input 5V p-p Sinewave**
- **CMRR = 20 log** $\frac{\text{A diff}}{\text{Acm}}$
- **1% Resistors Used For R3, R4, R25, R26**
- **Test Data**

Frequency	**CMR**
<100 KHz	94 dB
250 KHz	88 dB
650 KHz	82 dB
1 Mhz	78 dB
2 MHz	75 dB
3 MHz	60 dB
4 MHz	59 dB
5 MHz	63 dB
6 MHz	66 dB
7 MHz	68 dB
8 MHz	70 dB
9 MHz	72 dB
10 MHz	74 dB

- **CMRR And Integrator Filtering Eliminates Power Supply Noise Impacts On NEDT**

Detector Electronics Unit
Common Mode Test Circuit



PARTS

RESISTORS - RNC50 +/-1% THRU HOLE / PRECISION RPF01 OR EQUIVALENT

AD829 - 8 PIN DIP- ON SOCKETS

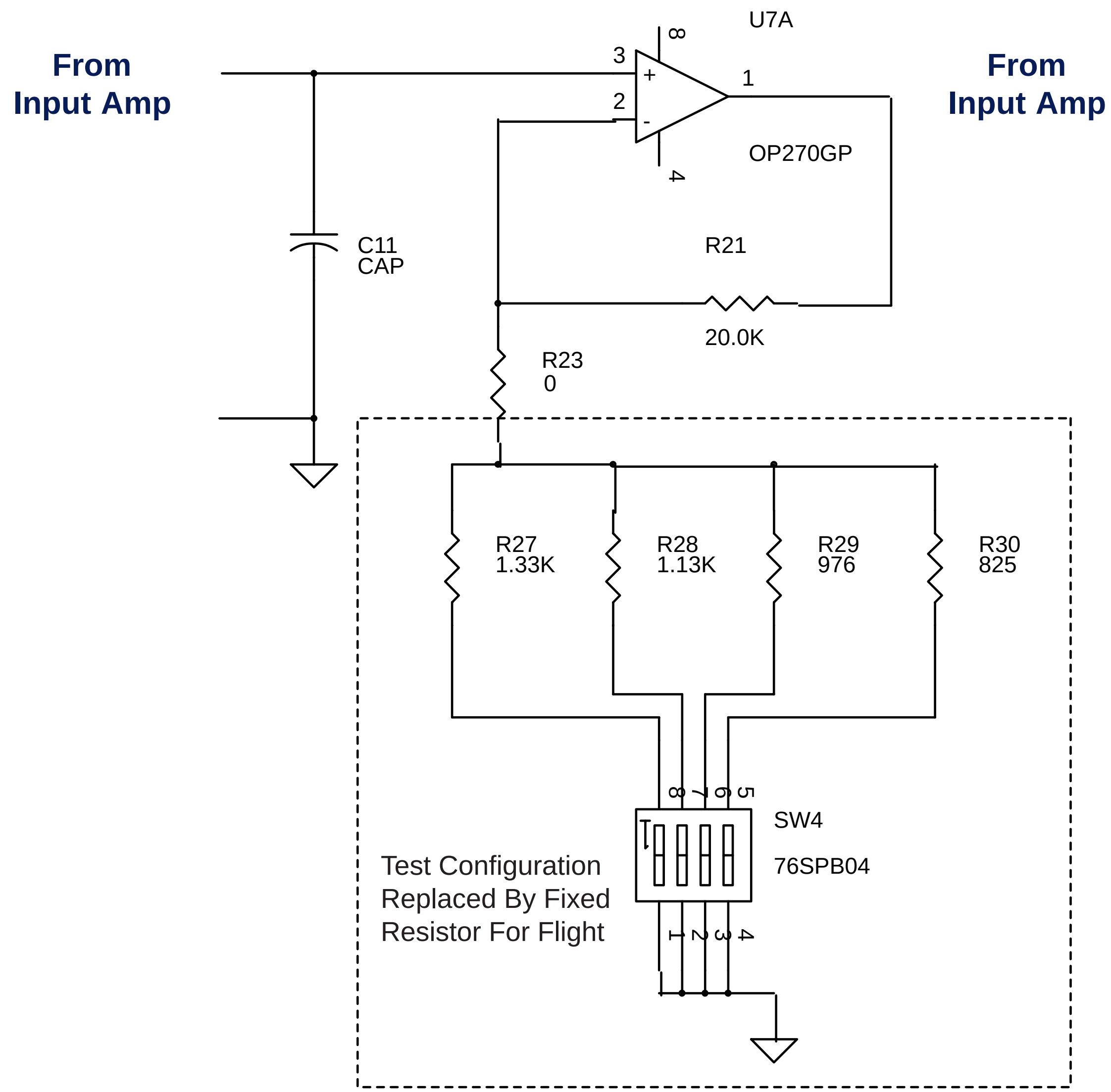
CAPACITORS
- .1 UF - M39014/01-1593
- 10UF - CWR06KH106KB
- 4.7 PF - 100B047KW 500X QK7000

LAYOUT

RF TECHNIQUES
COMPS PLACEMENT CRITICAL
LEAD LENGTHS CRITICAL
TWO- GND SYSTEM

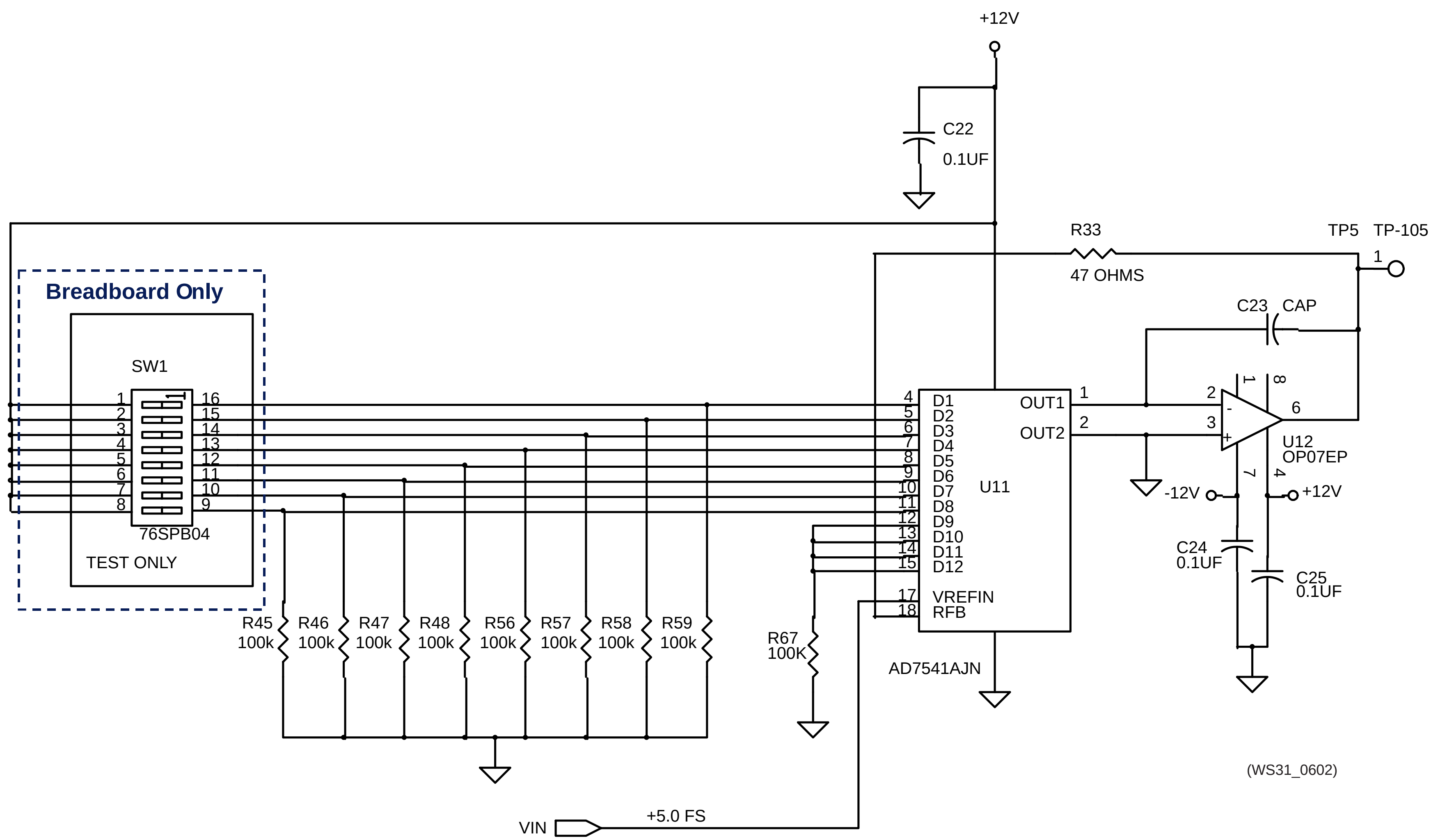
(WS33_0602)

Detector Electronics Unit
Coarse Gain Adjustment (Set At Test)

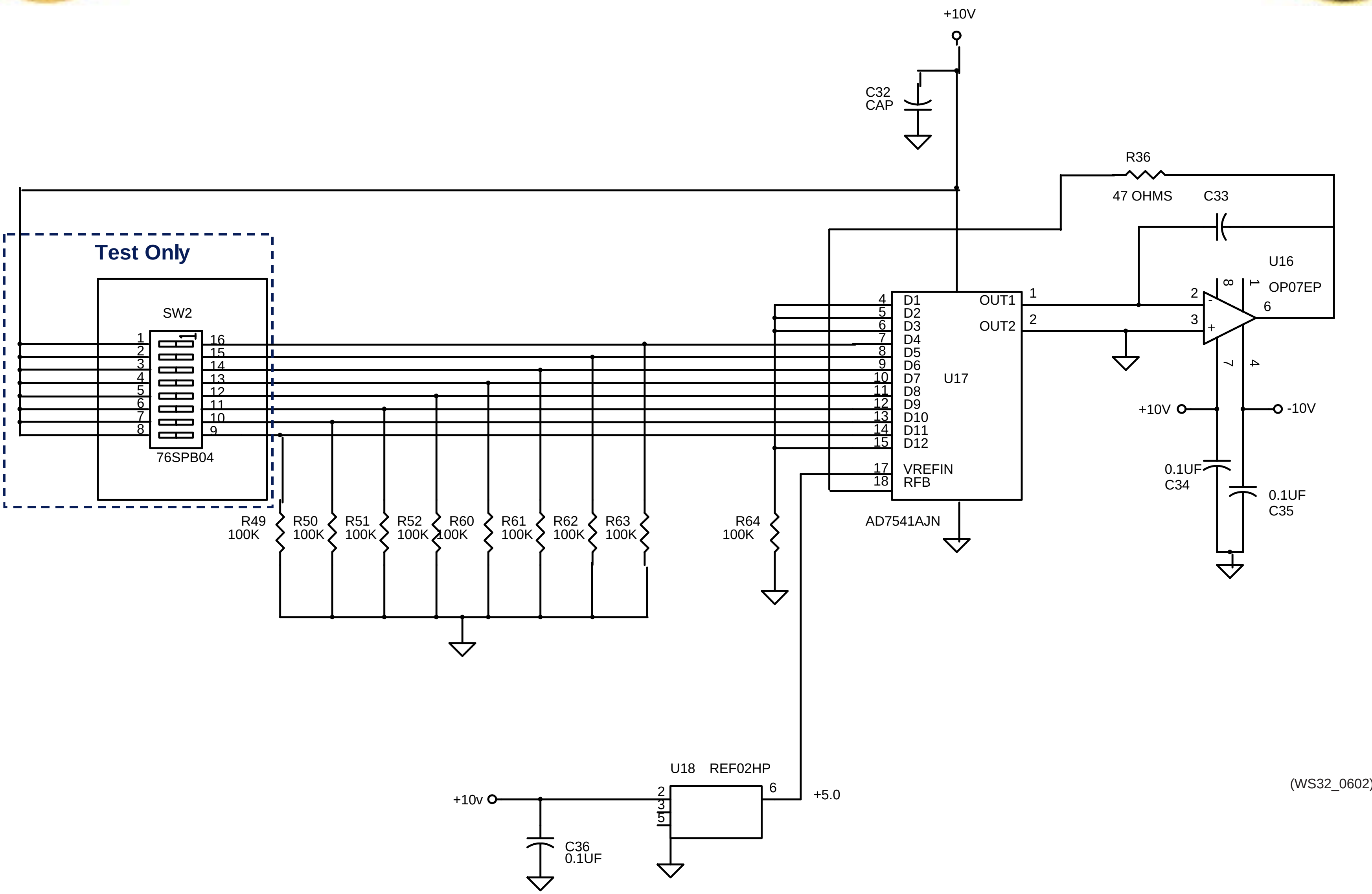


(WS30_0602)

Detector Electronics Unit
In-Flight Gain Adjustment Circuit



Detector Electronics Unit
In-Flight DC Offset Adjustment



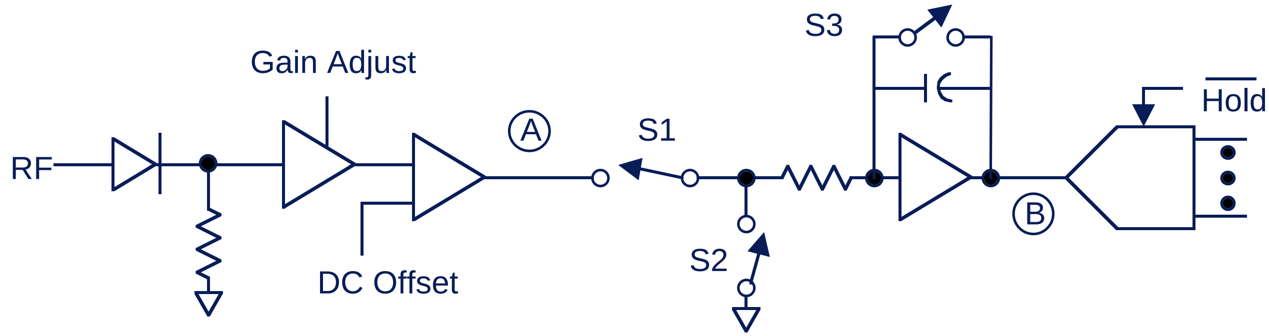
(WS32_0602)

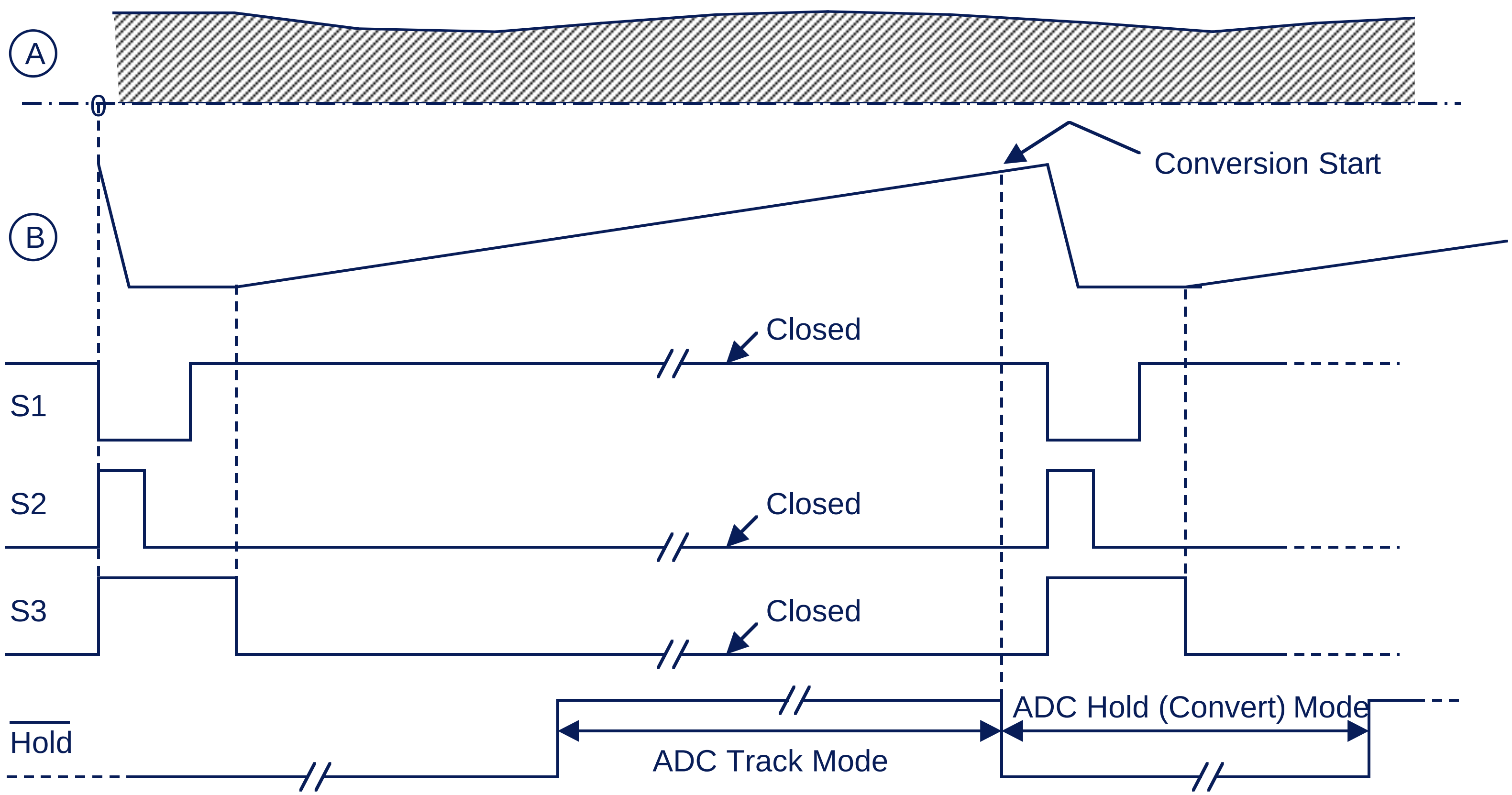
Detector Electronics Unit
Gain And Offset Adjustments

- **Offset Adjustment**
  - **Maximum: -625.6 Millivolt**
  - **Minimum: 0**
  - **Number Of Steps: 32**
  - **Resolution: .27dB Or 3.2% Each Step**

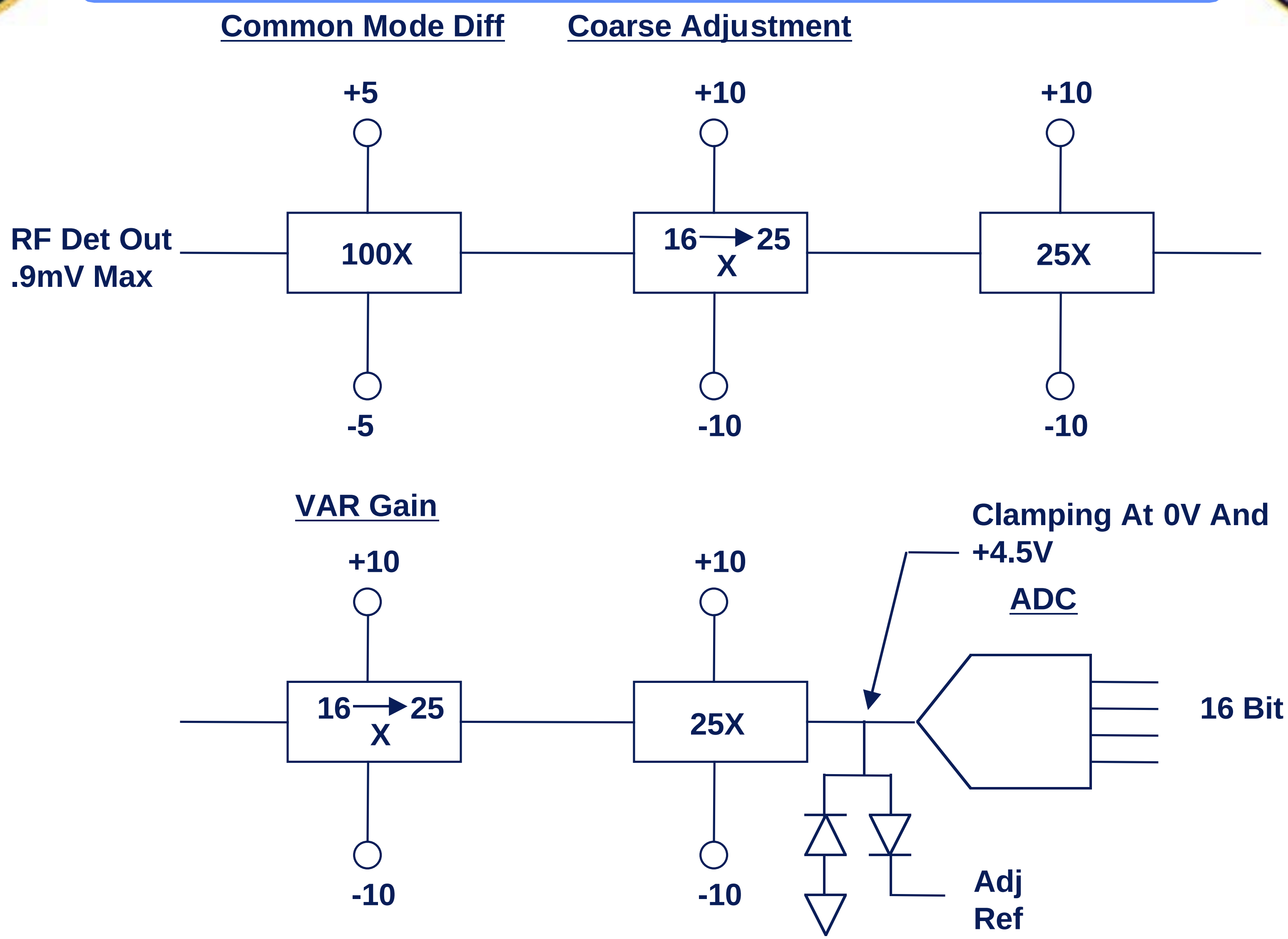
- **Gain Adjustment**
  - **Maximum: ~1.0 X**
  - **Minimum: 0.015 X**
  - **Range: 36.5dB In 128 Steps**
  - **Resolution .29 dB Each Step**

Detector Electronics Unit
Timing Sequence





Detector Electronics Unit
Input Dynamic Range Performance



Audio Circuitry is linear beyond ADC range and gain is set to not overflow ADC, therefore input signal will not be distorted over full dynamic range

Test: Crystal CS5016 ADC Evaluation Board

Test: Crystal CS5016 ADC Evaluation Board With Constant DC Input

Input Voltage: 3 VDC (F.S.=4.5V)
Number of Samples Collected: 1024
16-bit number of codes: 65,536
LSB: 68.6 microvolt

Measurement Data:

Mean Value = 11,110.07

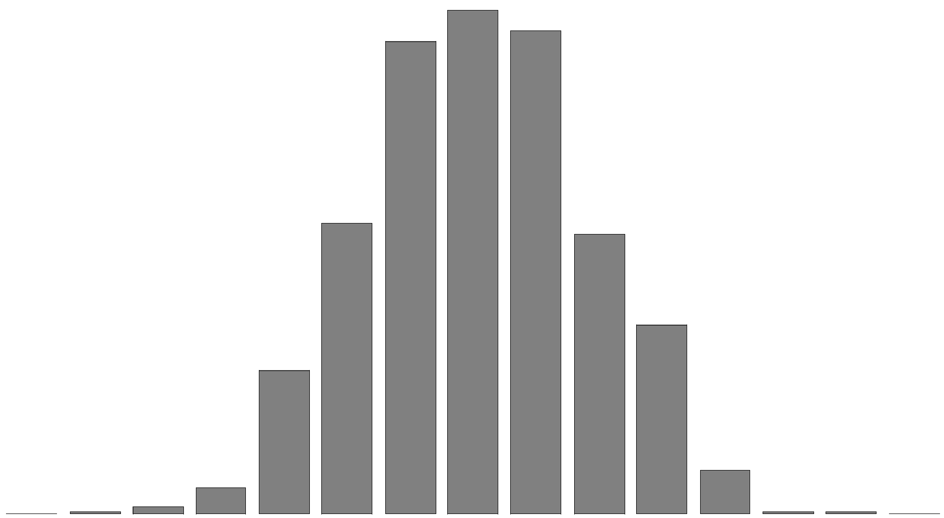
Standard Deviation = 1.78

Variance = 3.16

Minimum Value =11,104

Maximum Value = 11,116

ENOB= 15.17 bits



Noise Analysis

- System Minimum ENOB = 14
- 14 ENOB $\equiv$ $\log^2 \dfrac{4.5}{\text{RMS Noise}}$
- RMS Noise = 275µV
- Quantization Noise = 80µV
- ADC Noise = 37.7µV
- Analog Circuits = XµV
- $(275)^2 = (80)^2 + (37.7)^2 + (x)^2$

  X = 260µV
- Analog Noise Level Must Be ≤260 µV
- Integrator Noise Band Width (37 GHz) = 1127 Hz

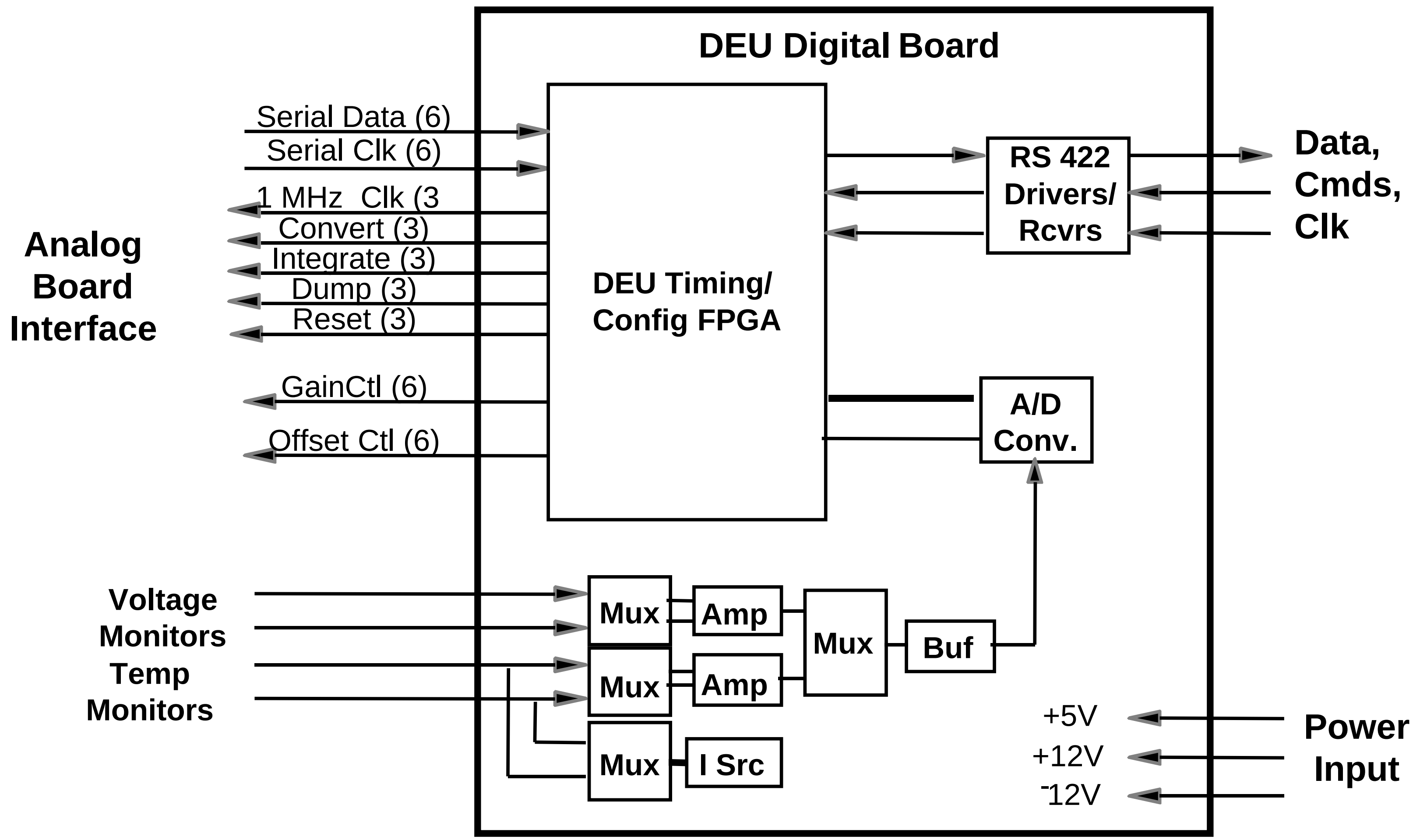
  Gain ≤ 260 µV/(2.4nV/$\sqrt{\text{Hz}}$ x $\sqrt{1127}$)
- Maximum Gain = 2240

Payload Receiver Subsystem
Digital Design

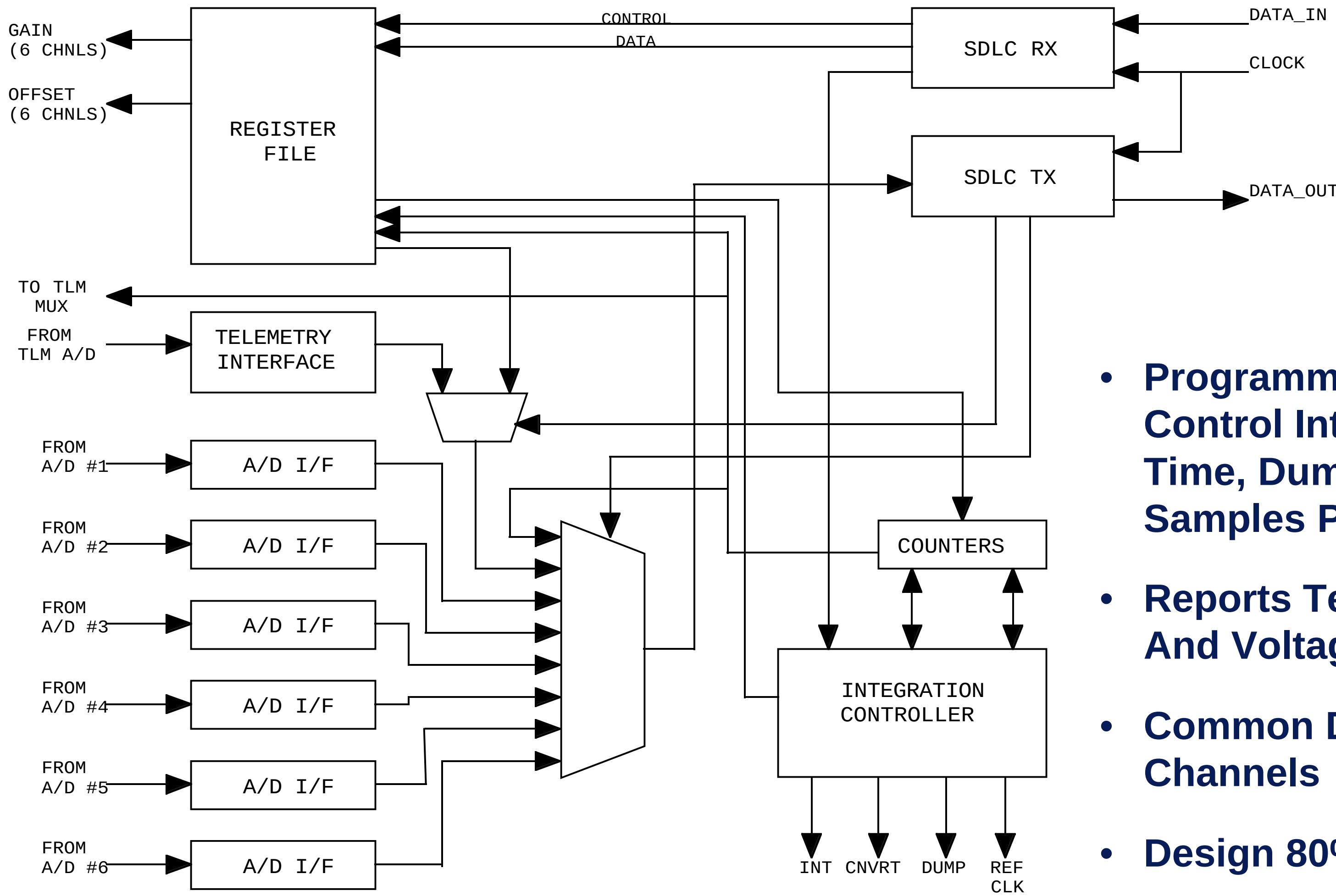
DEU Digital Board Requirements

- Accept Commands And Clock From RDHU
- Provide 1 MHz Clock To Audio Processor
- Provide Integrate, Dump, Convert, And Reset Signals To Audio Processor
- Provide Gain And Offset Control To Audio Processor
- Accept Serial Data And Serial Clock From Audio Processor
- Accept Voltage Monitor And Temp Monitor Analog Telemetry Signals
- Perform A/D Conversion Of Analog Telemetry
- Combine Receiver Data And Telemetry Data Into One Serial Data Stream To The RDHU

DEU Digital Board Block Diagram



DEU FPGA Block Diagram



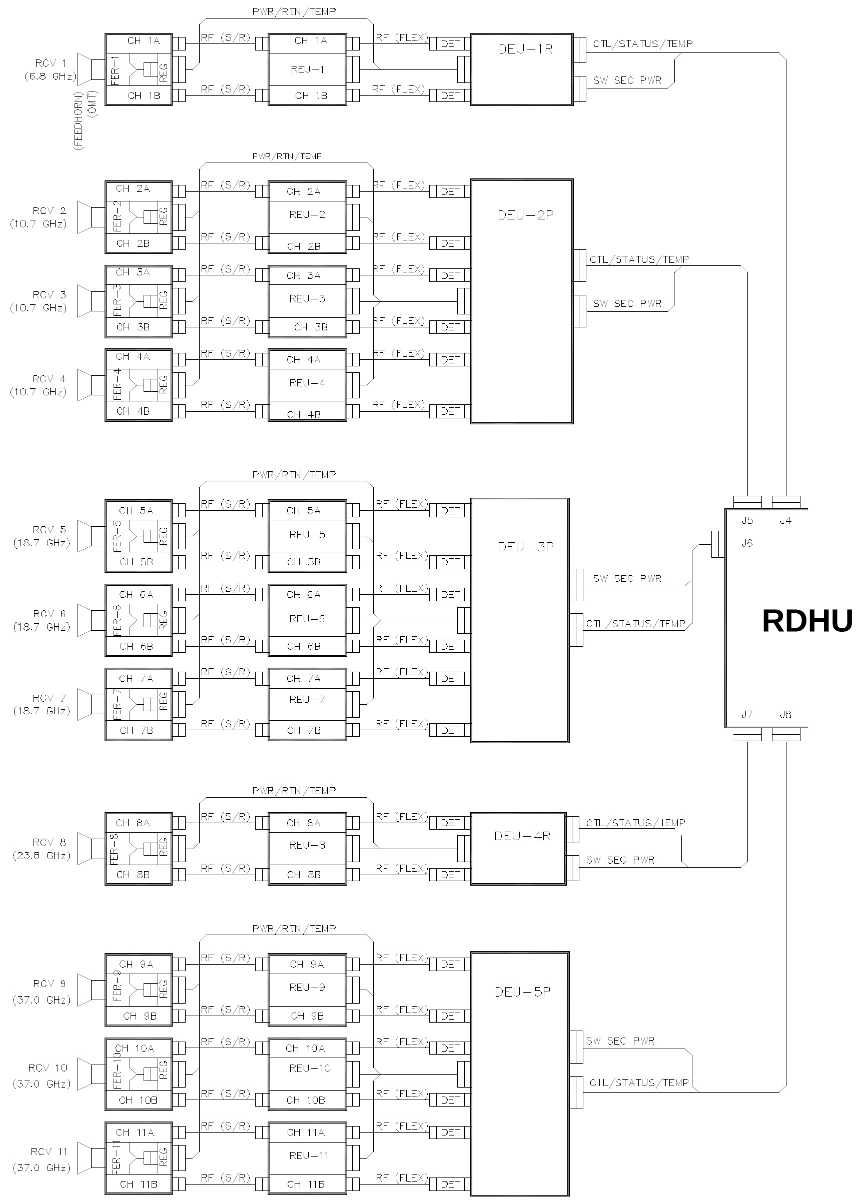
- **Programmable Settings Control Integrated Time, Dump Time, # Samples Per Spin**
- **Reports Temperature And Voltage / Telemetry**
- **Common Design All Channels**
- **Design 80% Complete**

Payload Receiver Subsystem

Mechanical Design

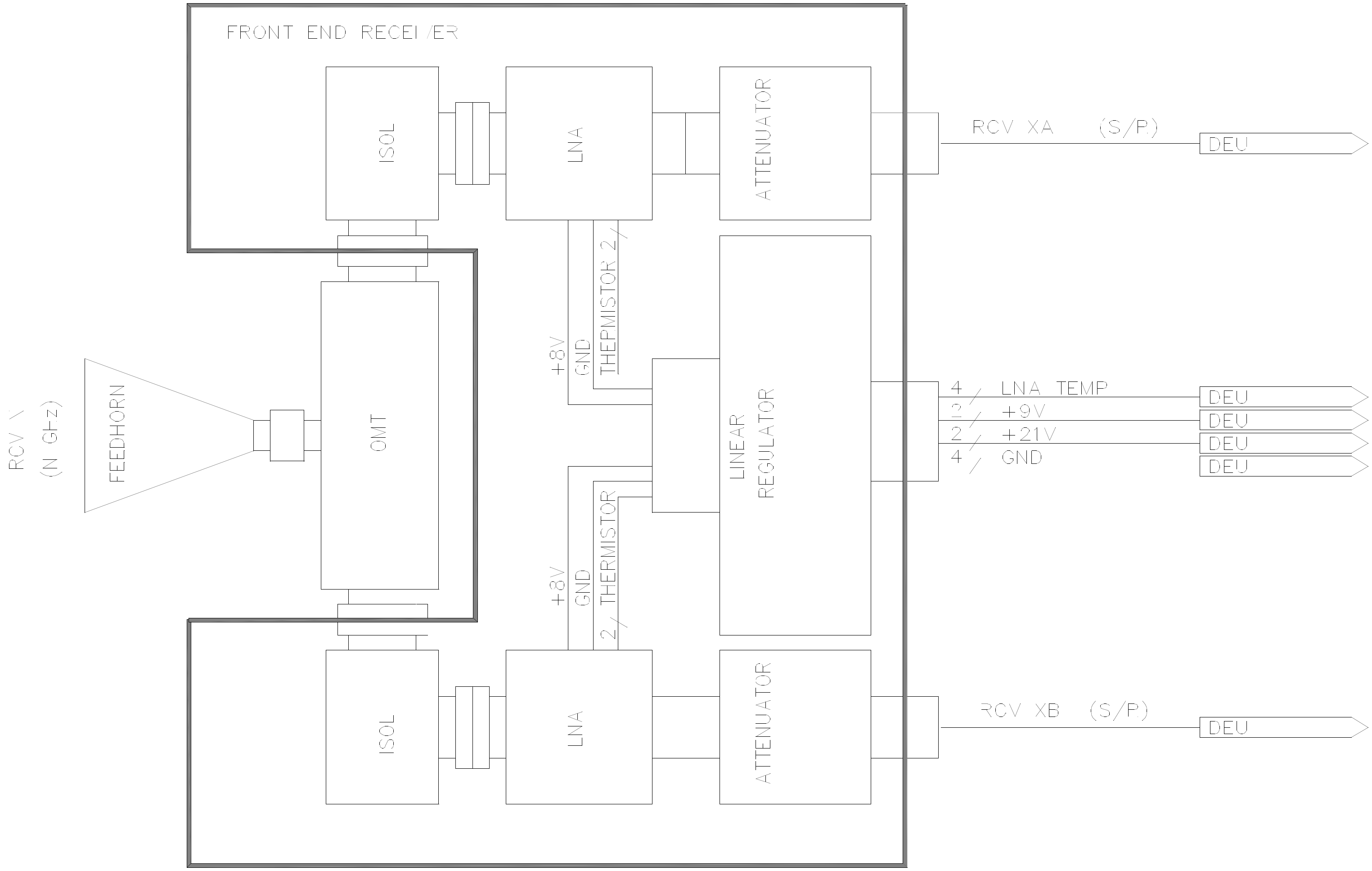
Receiver Electronics Interconnect Diagram

Rotating Payload Electronics

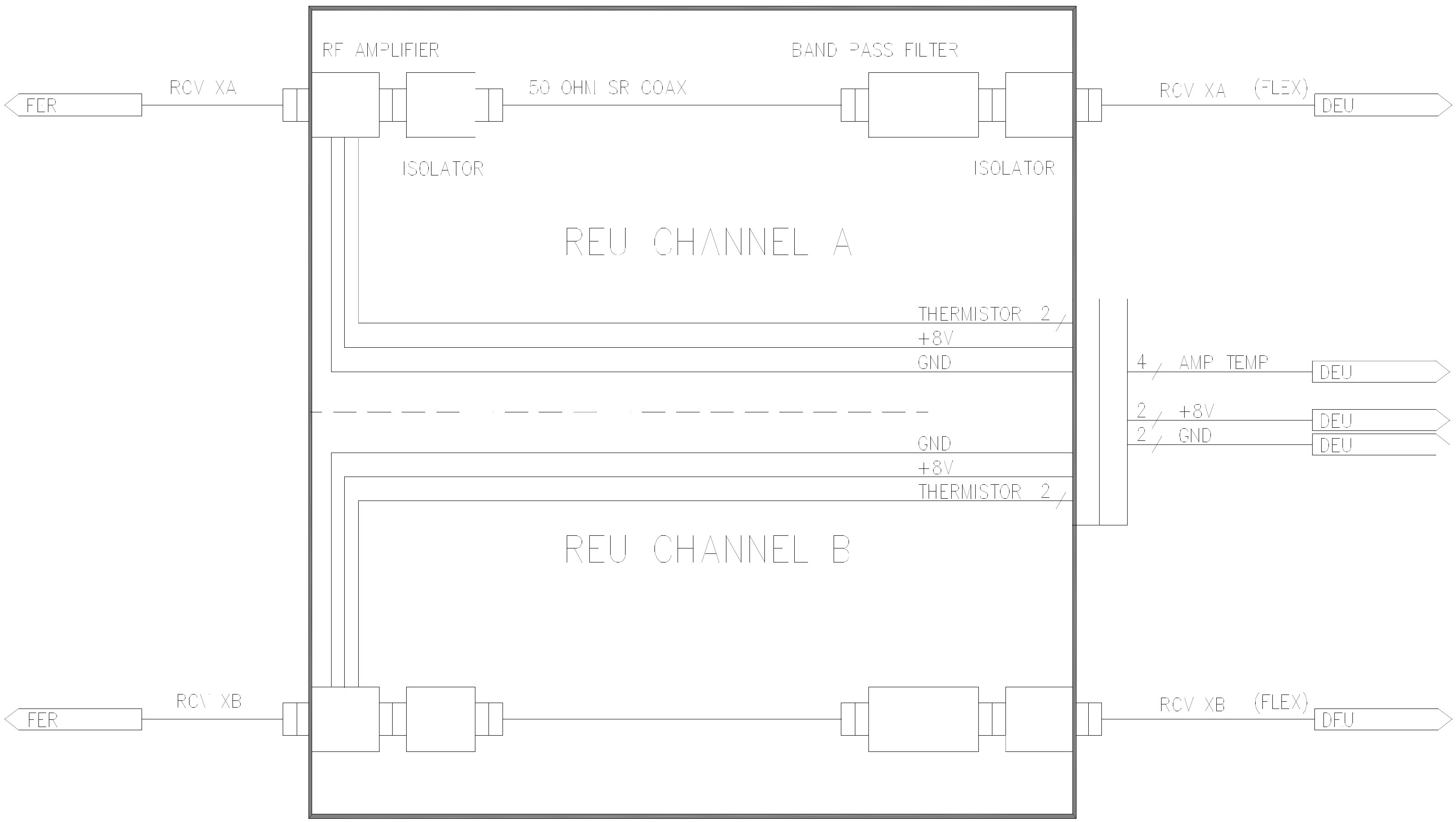


980610_WS_PDR_PayloadRcvr.46

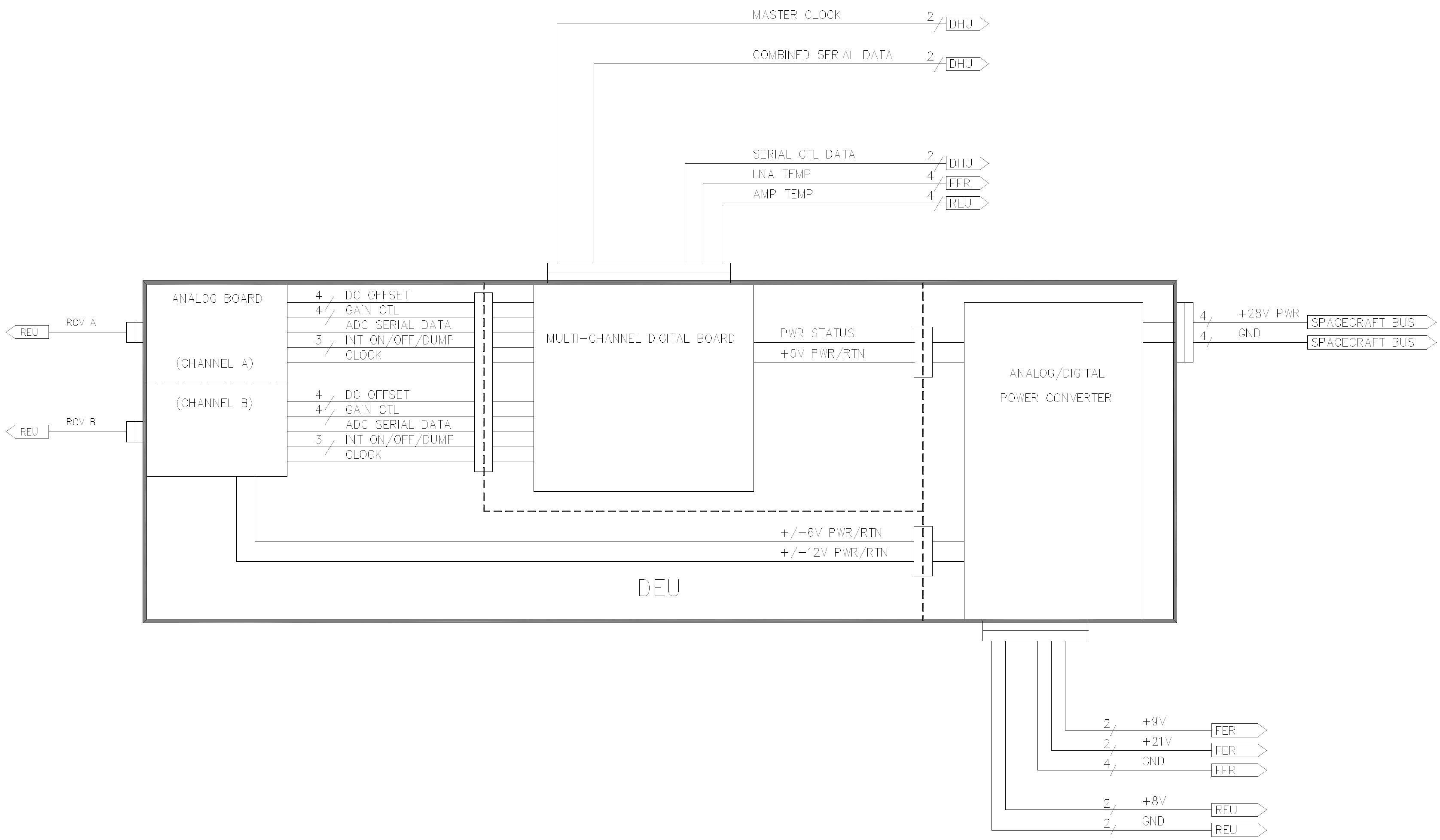
Front End Receiver (FER) Interconnect



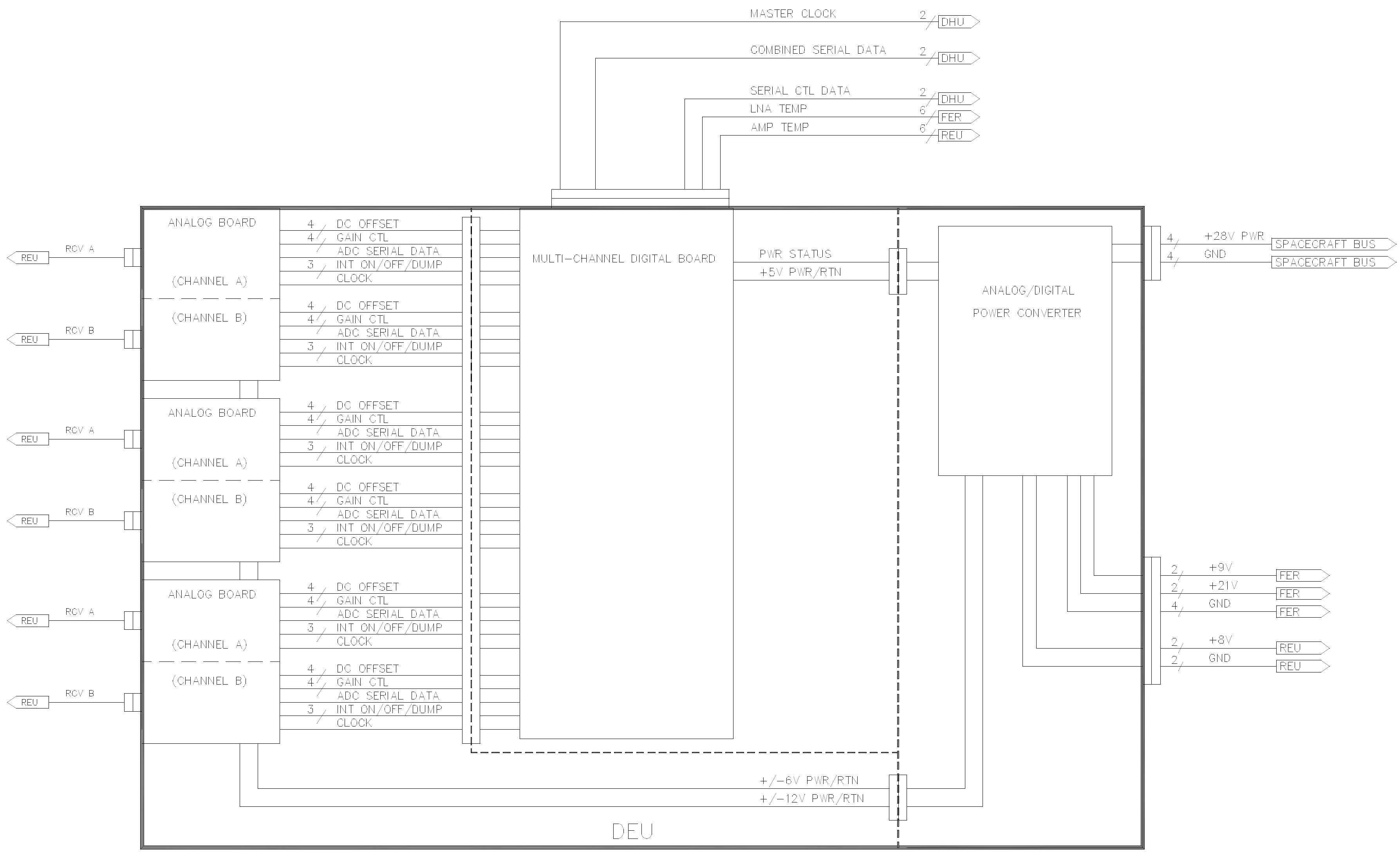
Receiver Electronics Unit (REU) Interconnect Diagram



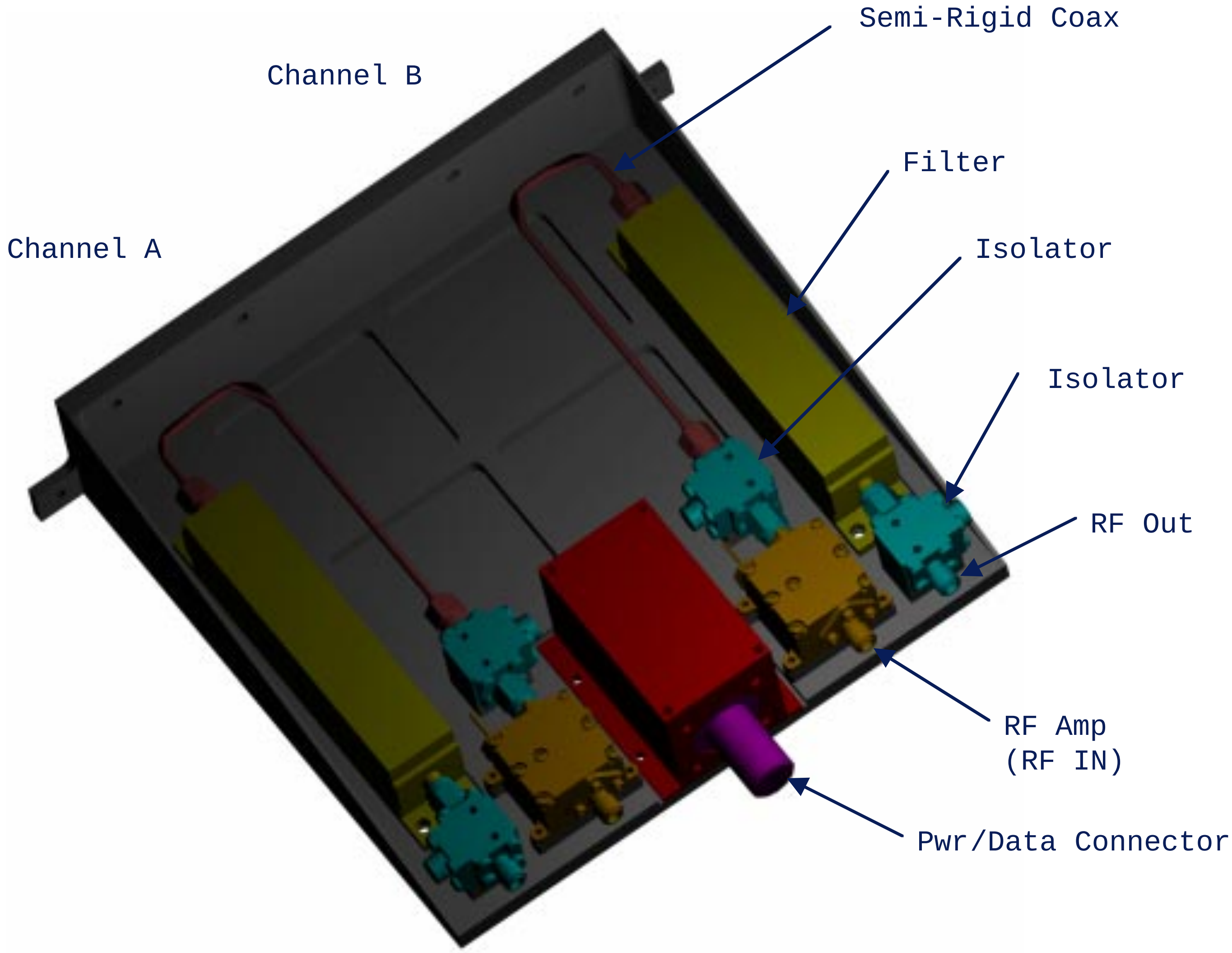
DEU (2 Channel) Interconnect Diagram



DEU (6 Channel) Interconnect Diagram



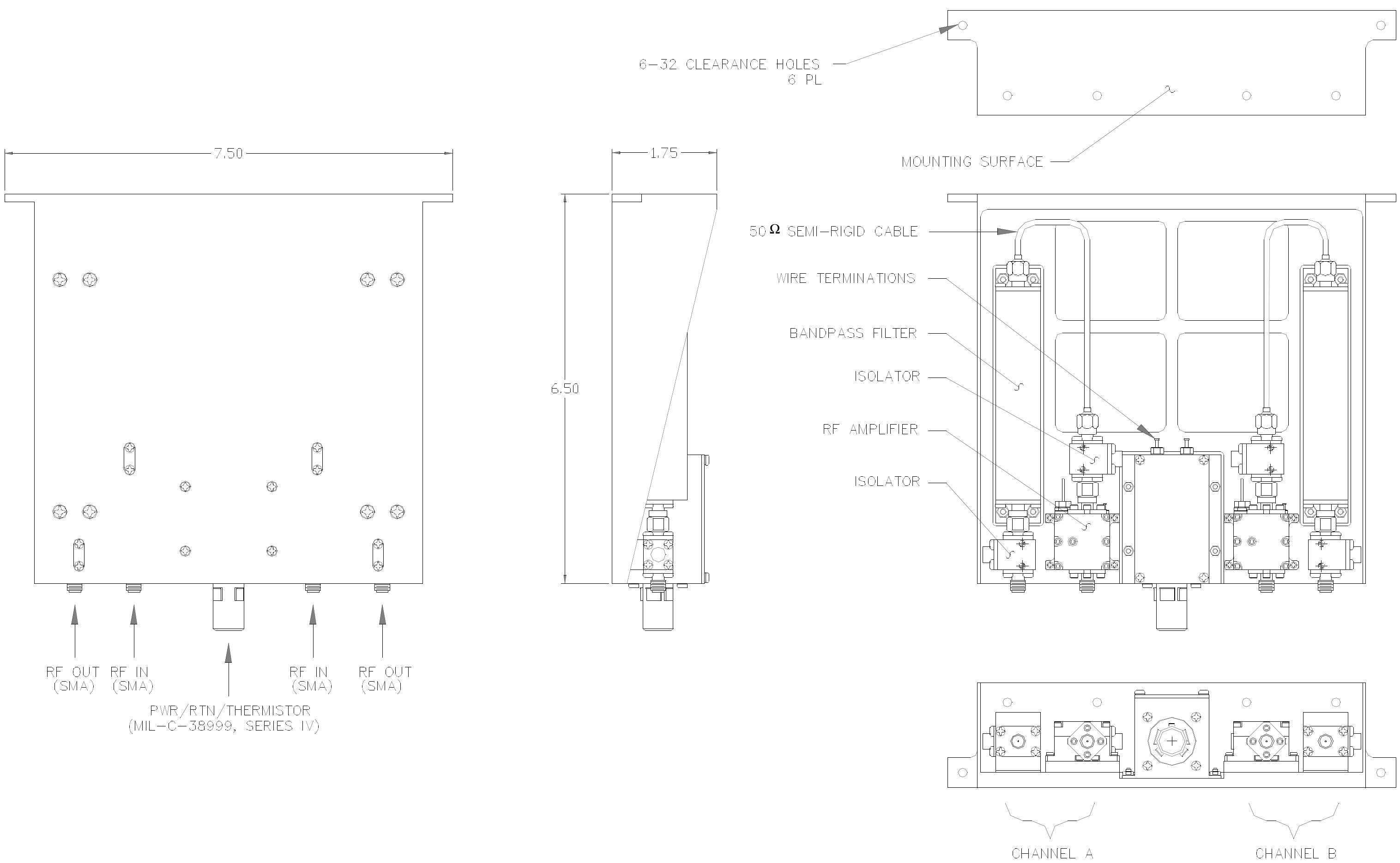
Receiver Electronics Unit (REU) Mechanical Envelope



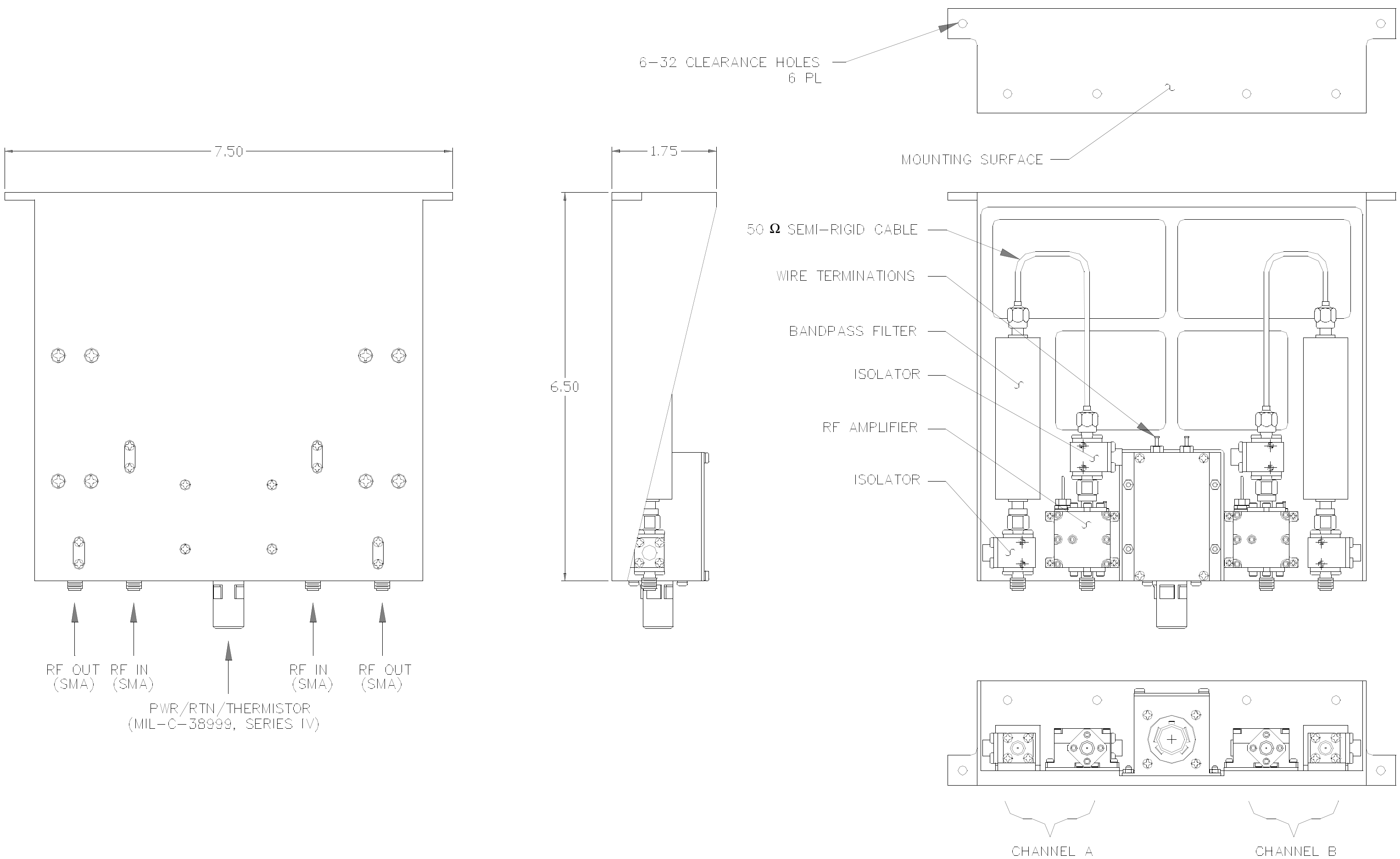
REU Packaging Features

- Open Style Packaging Approach Using SMA Connectorized RF Components.
- Low Loss, High Isolation Within The RF String.
- Common Bracket Design For 11 REU's With Component Mounting Variations.
- Machined Aluminum 6061-T6. Weight Reduction Pockets Planned As Design Progresses.

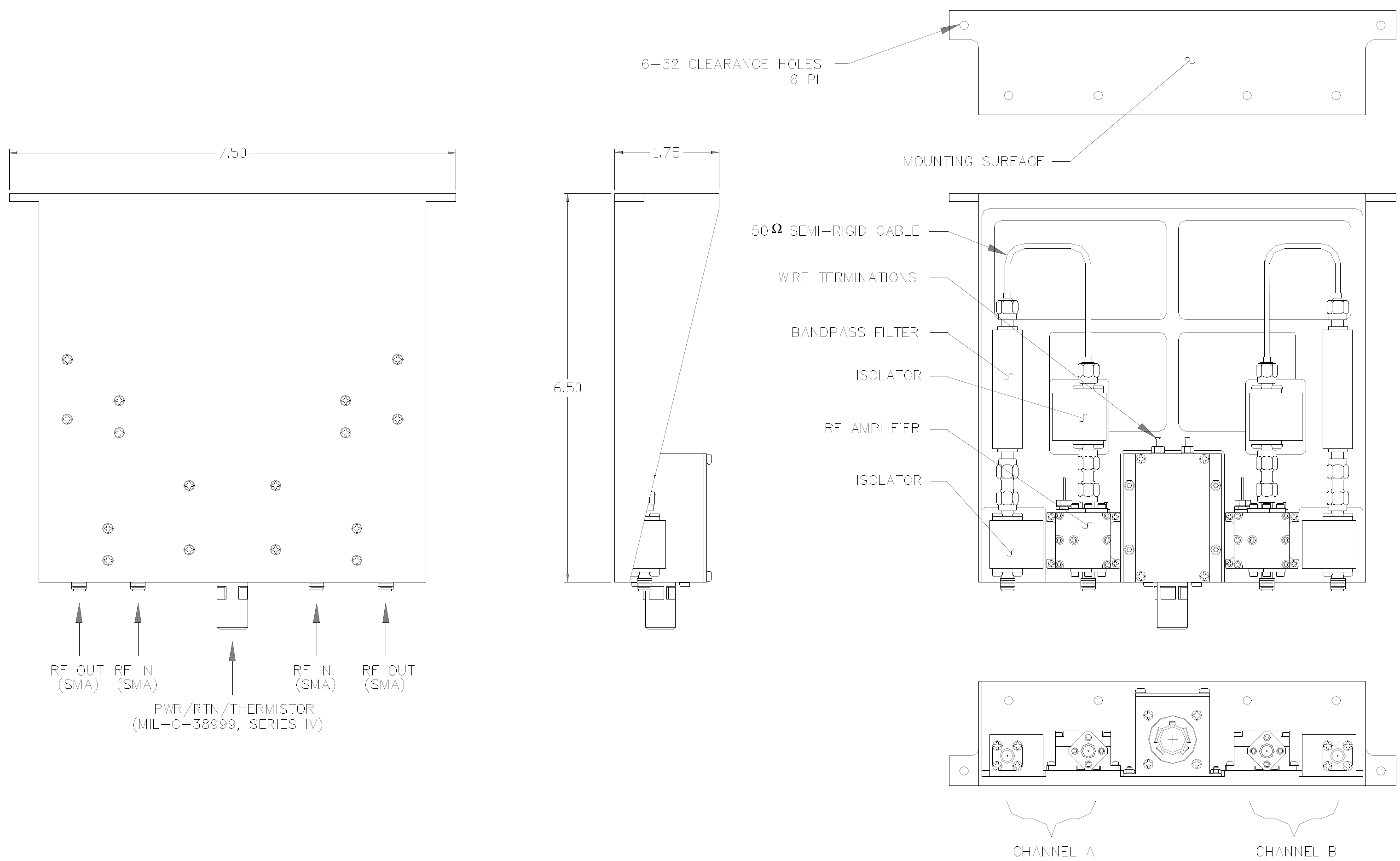
REU-1 (6.8 GHz) Mechanical Envelope



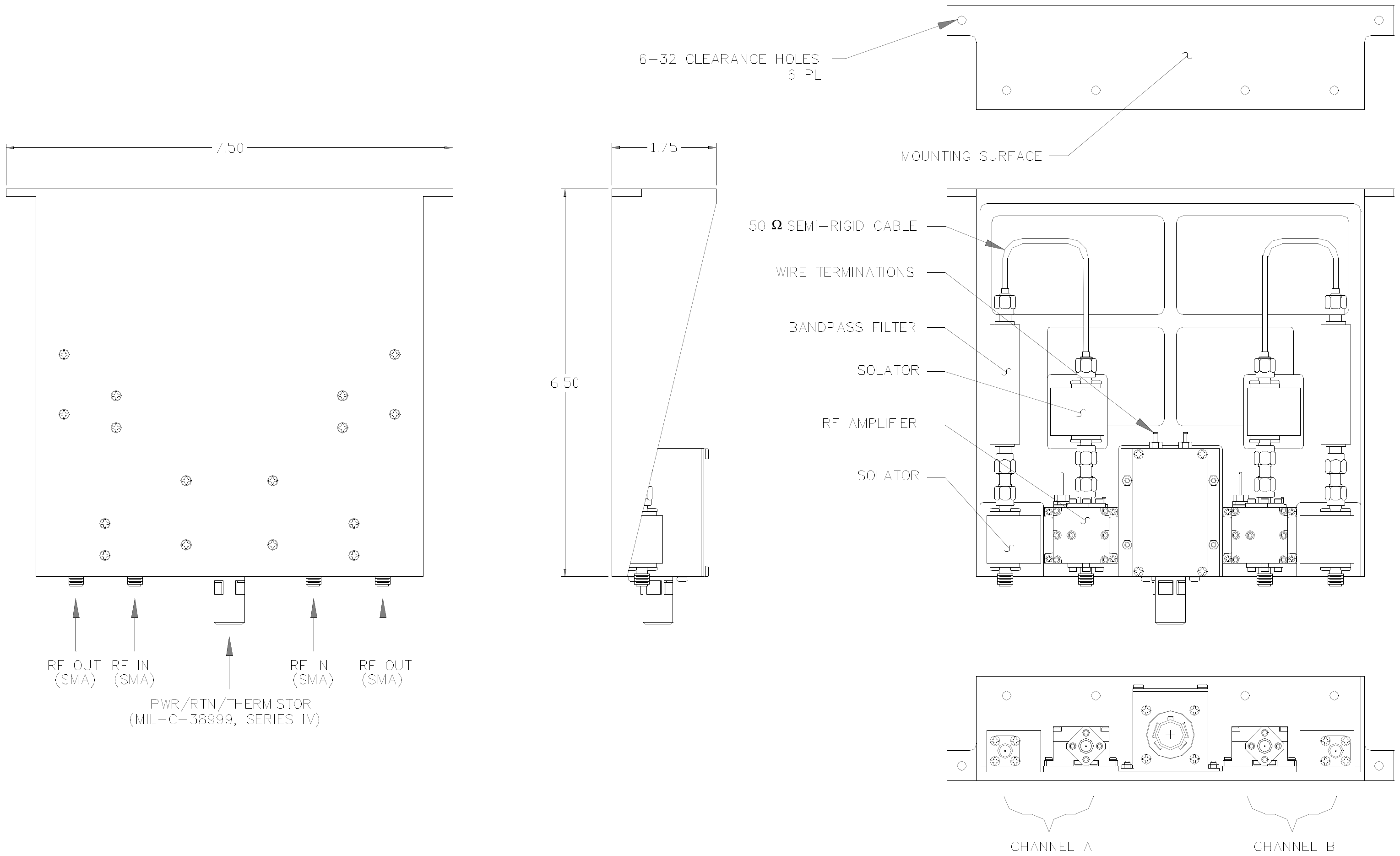
REU-2,3,4 (10.7 GHz) Mechanical Envelope



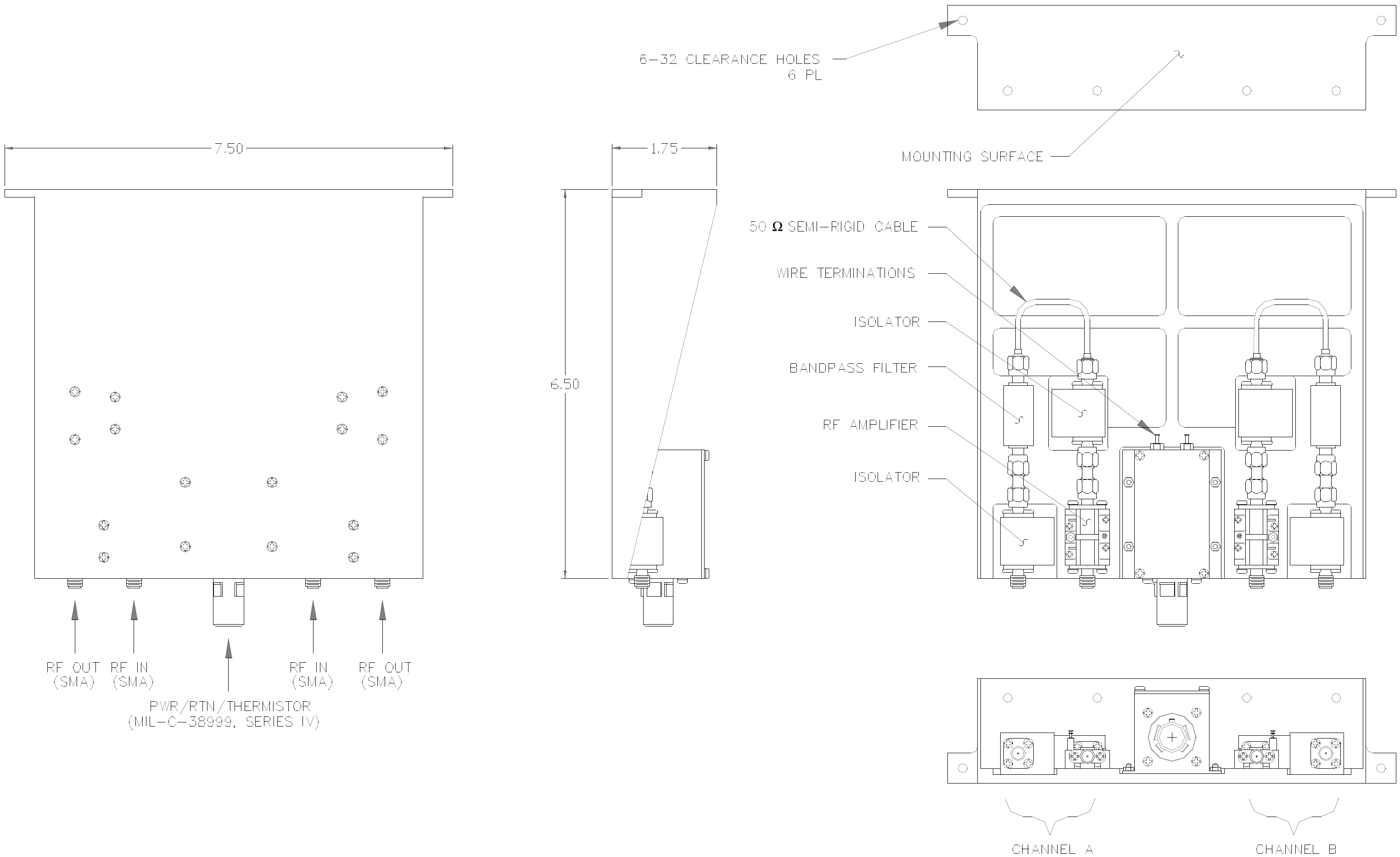
REU-5,6,7 (18.7 GHz) Mechanical Envelope



REU-8 (23.8 GHz) Mechanical Envelope



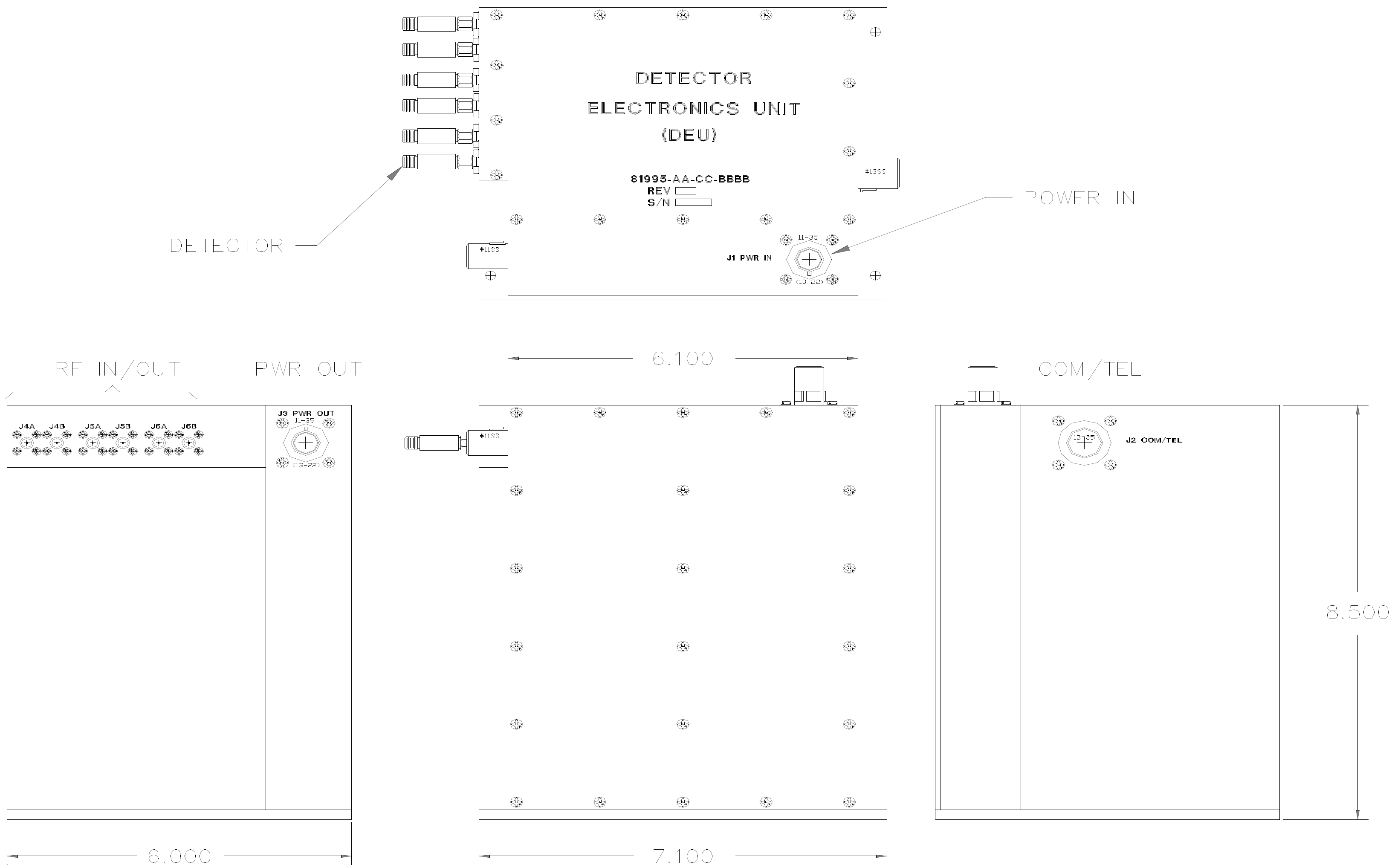
REU-9,10,11 (37.0 GHz) Mechanical Envelope



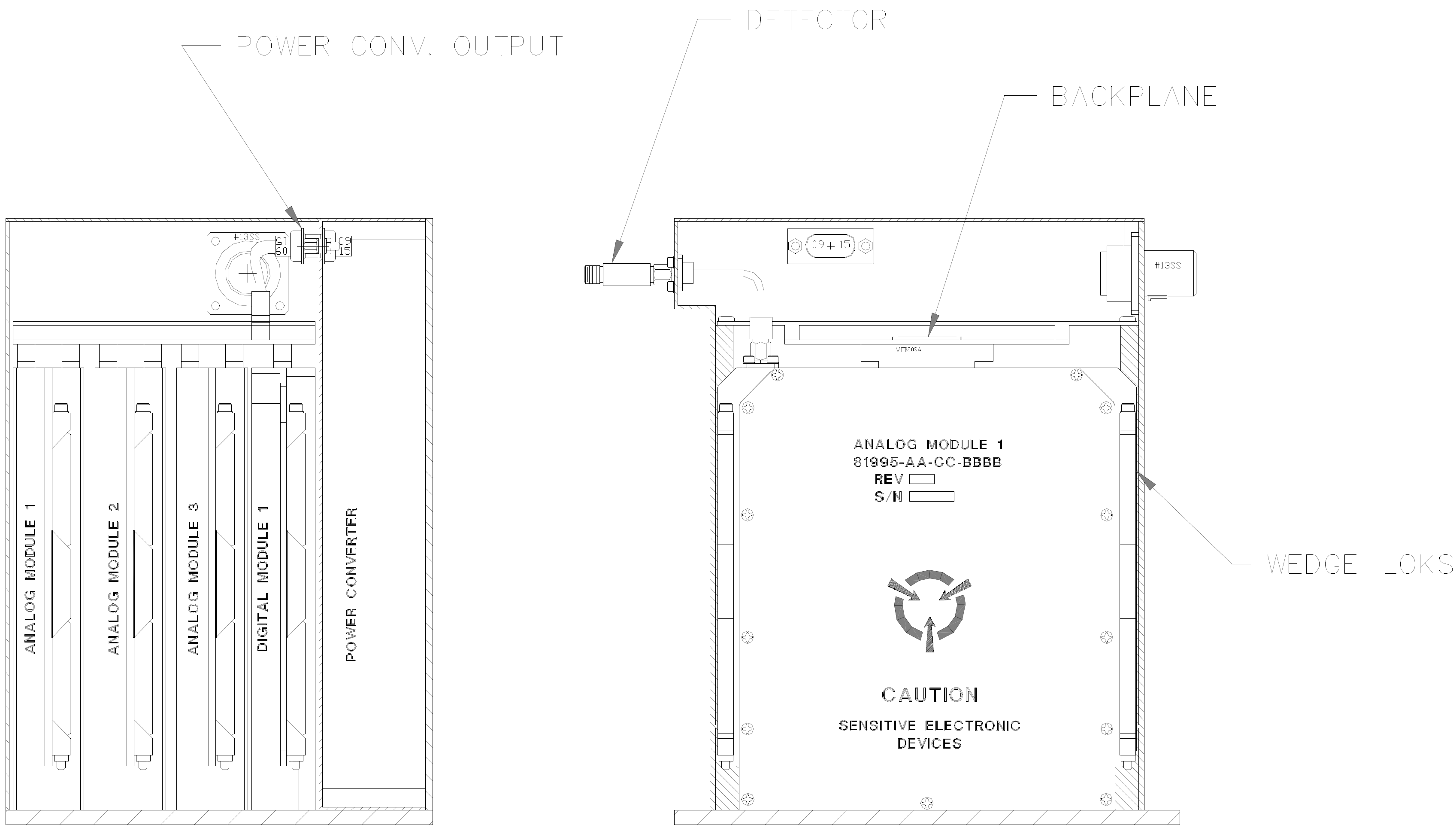
DEU Packaging Features

- Modular Design For 3 Primary Components: Power Converter, Digital Module, Analog Module.
- 6 Channel DEU Utilizes 3 Analog Modules.
- 2 Channel DEU Utilizes 1 Analog Module.
- High Isolation/Shielding Approach Utilizing EMI Filter Connectors At The Power Converter, Module Covers, Gasketed Enclosure Seams.
- Wedge-Loks On Modules For Thermal and Vibration Environment.
- Conduction Cooled Design From Component to Baseplate.
- Mil-C-38999 Series IV Connectors And Mil-C-17 SMA Connectors For Unit I/O. Mil-C-24308 D-Sub And Mil-C-55302 PCB Connectors.
- Black Thermal Control Paint.

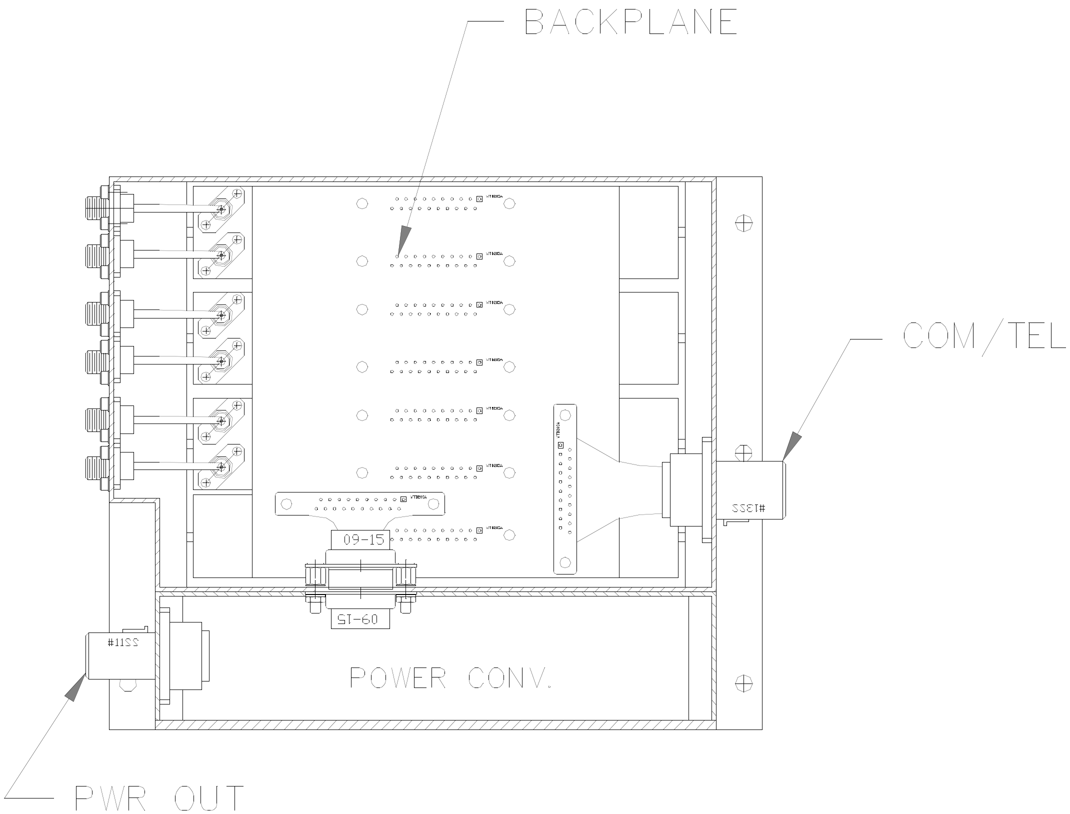
DEU (6 Channel) Mechanical Envelope



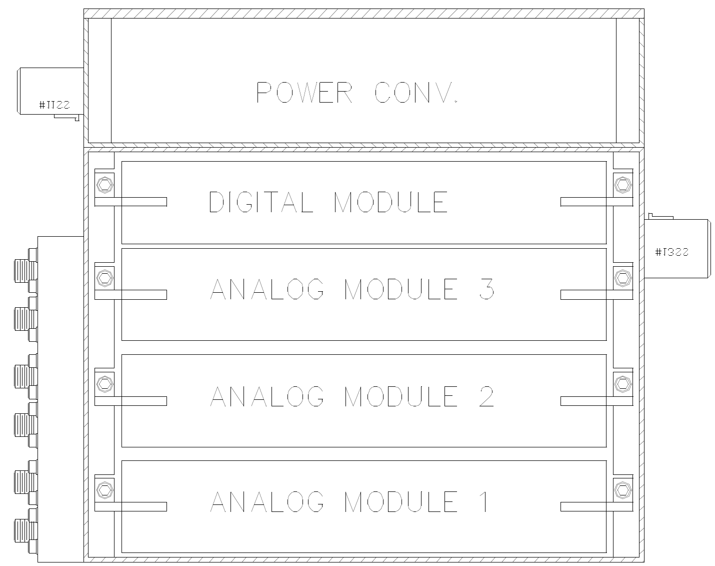
DEU Packaging Details (1 of 3)



DEU Packaging Details (2 of 3)

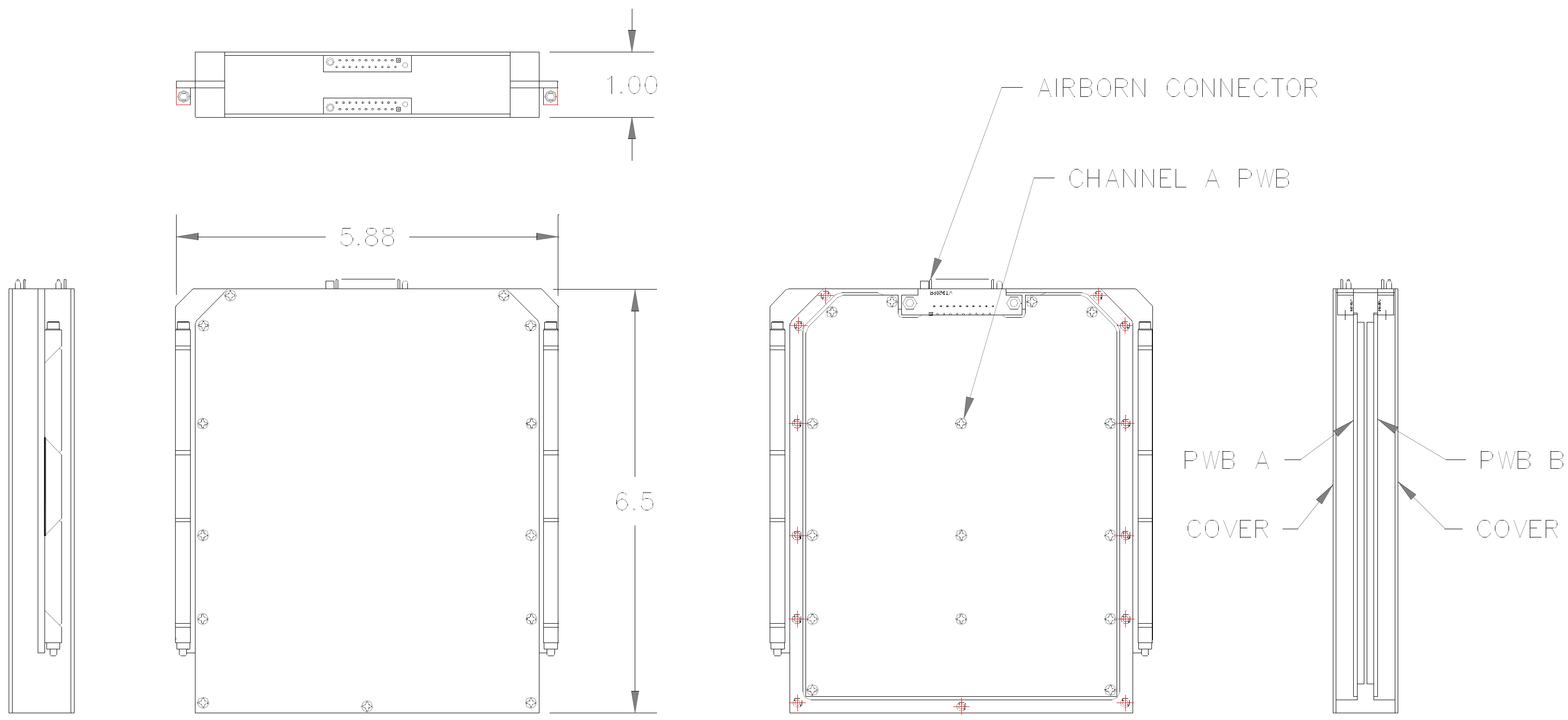


TOP VIEW
(TOP COVER REMOVED)

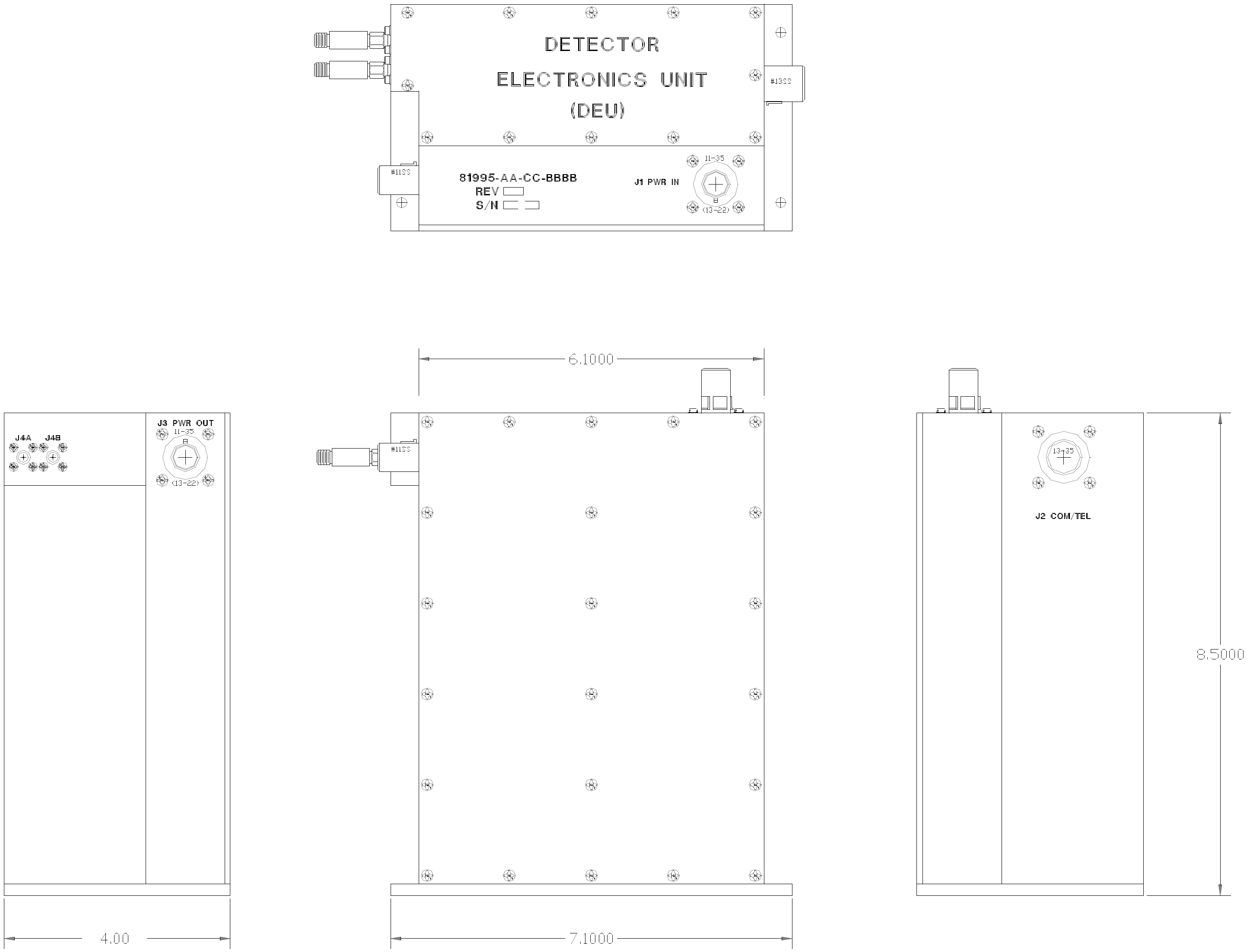


BOTTOM VIEW
(BASEPLATE REMOVED)

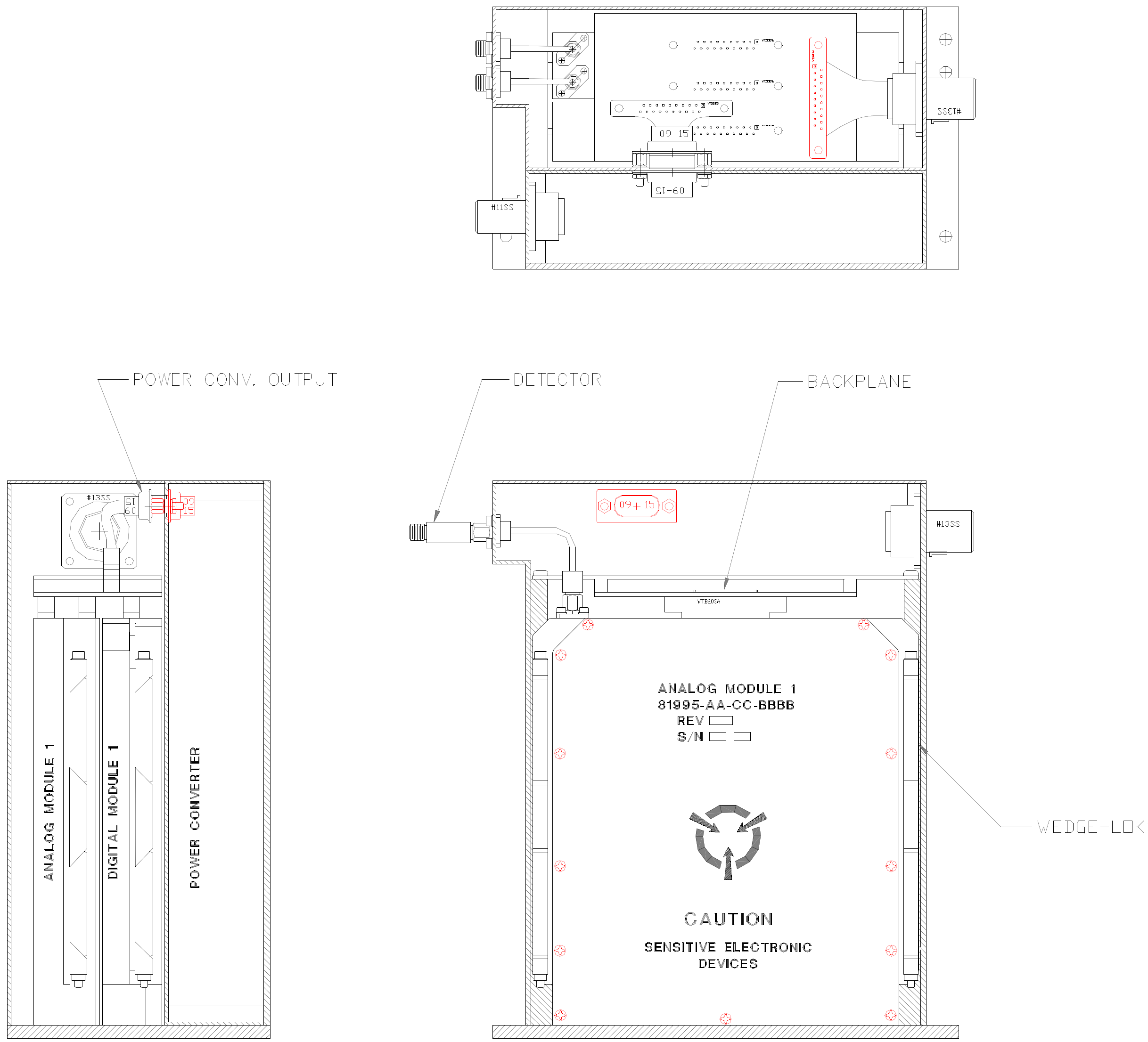
DEU Packaging Details (3 0f 3)



DEU (2 Channel) Mechanical Envelope



DEU (2 Channel) Packaging Details



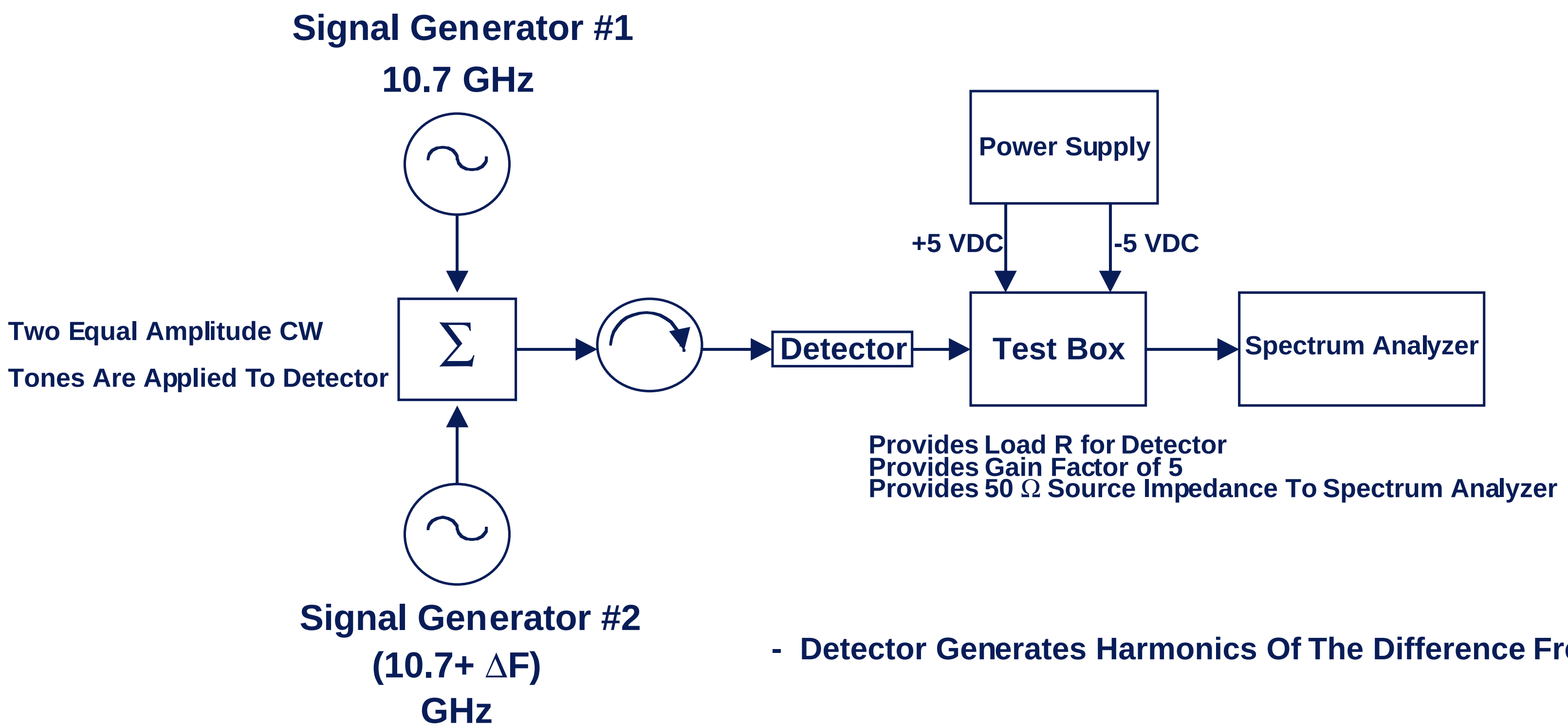
Payload Receiver Subsystem

Breadboard Design/Test

Breadboard Test Plan

- **Objective: Mitigate Risk Associated With State-Of-The-Art Radiometer Design**
  - **Verify Availability Of Components That Meet Allocated Requirements And Error Budgets**
  - **Validate Receiver Front End Performance**
  - **Validate Audio Processor Performance**
- **Approach: Progression Of Component, Functional, And Integrated Testing**
  - **RF Detector Linearity**
  - **LNA, RFA, Isolator, Filter Characterization**
  - **RF Front End Characterization**
    - **Noise Figures**
    - **Amplitude / Frequency Response**
    - **1dB Compression**
  - **ADC Characterization**
  - **Audio Processor Characterization**
  - **Integrated Receiver Testing**

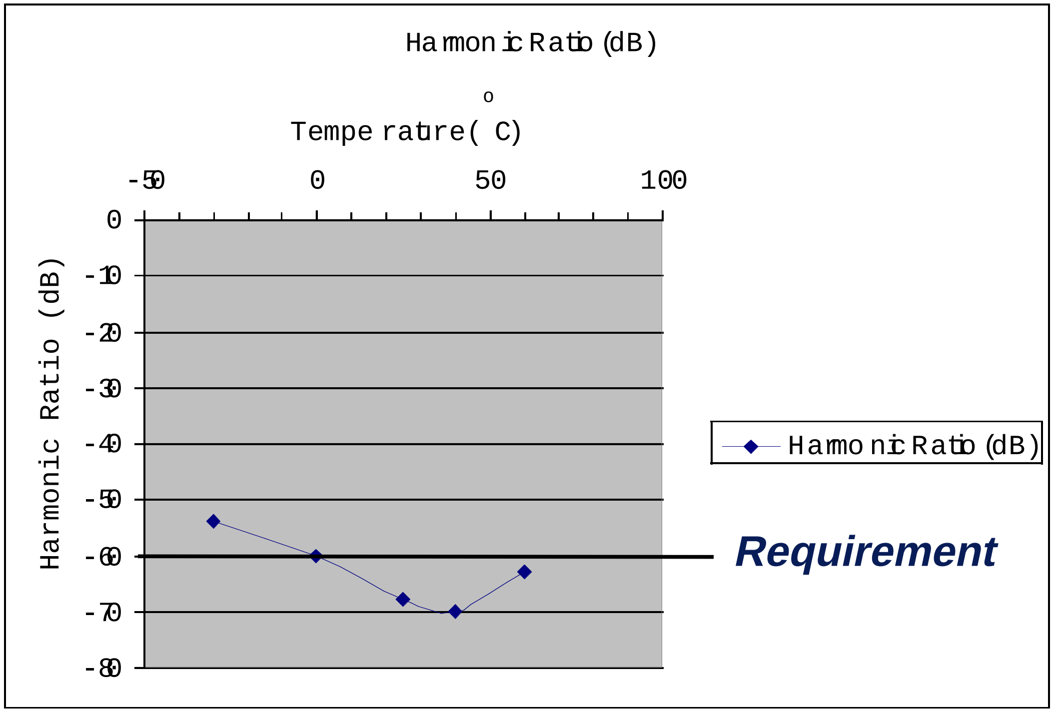
Detector Linearity Characterization Measurement



- Detector Generates Harmonics Of The Difference Frequency.
- The First Audio Tone Is Proportional To X^2, The Second Is Proportional To X^4.
- 0.1% Linearity Is Equivalent To -60 dB Ratio Of X^4 To X^2.

Detector Linearity Characterization Measurement Results

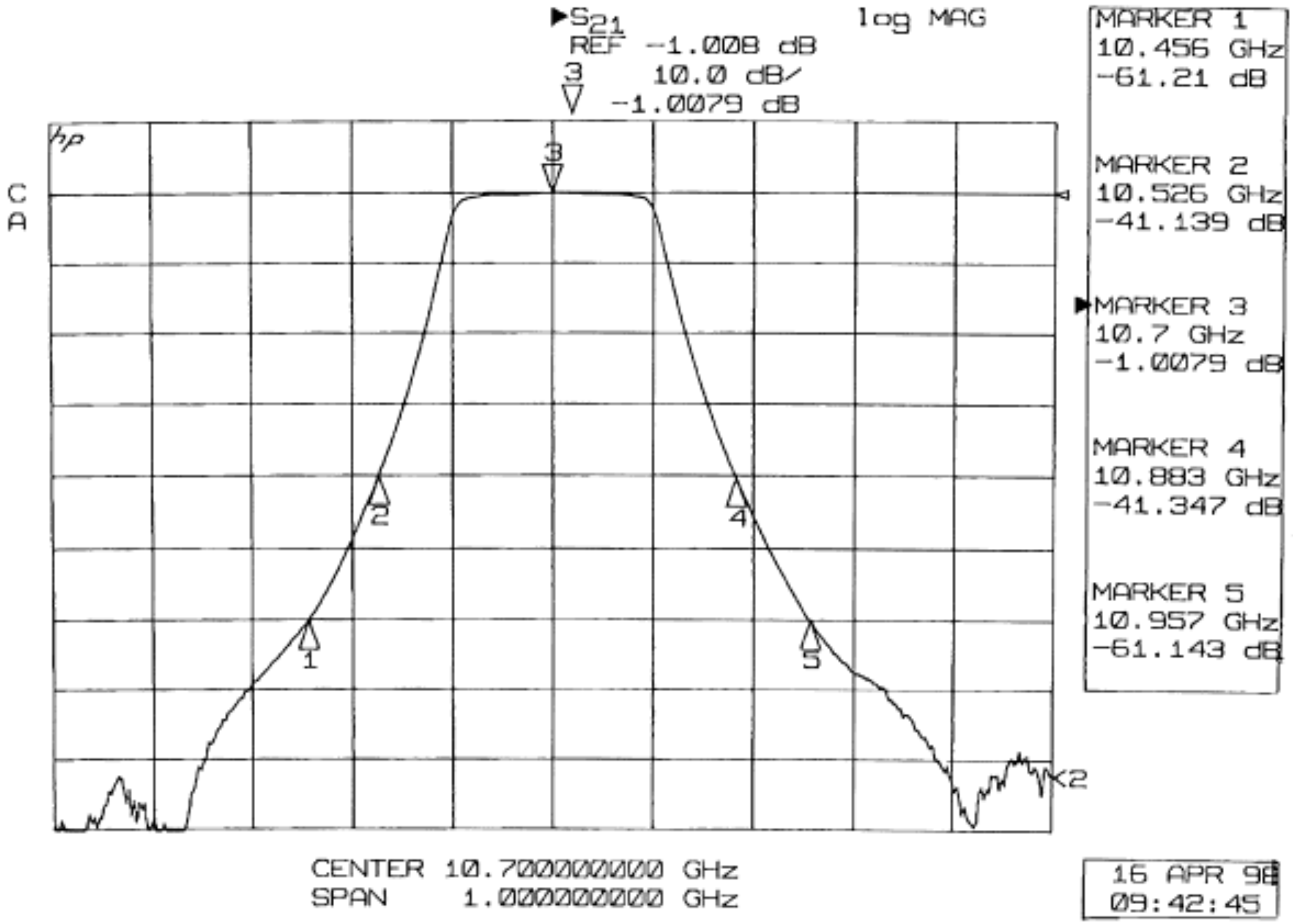
- **Detector Linearity Has Been Shown To Be A Function Of Detector Load Resistance.**
- **Tests On Two Detectors Showed Loading Optimization Resulted In $\leq$-60dB Harmonic Ratios Over 0 To 40°C .**
- **Results Were < -50 dB Over -30 To +60°C.**
- **The Detector Load Resistance Will Be A Set At Test Value To Insure Acceptable Linearity Of The WindSat Detectors.**



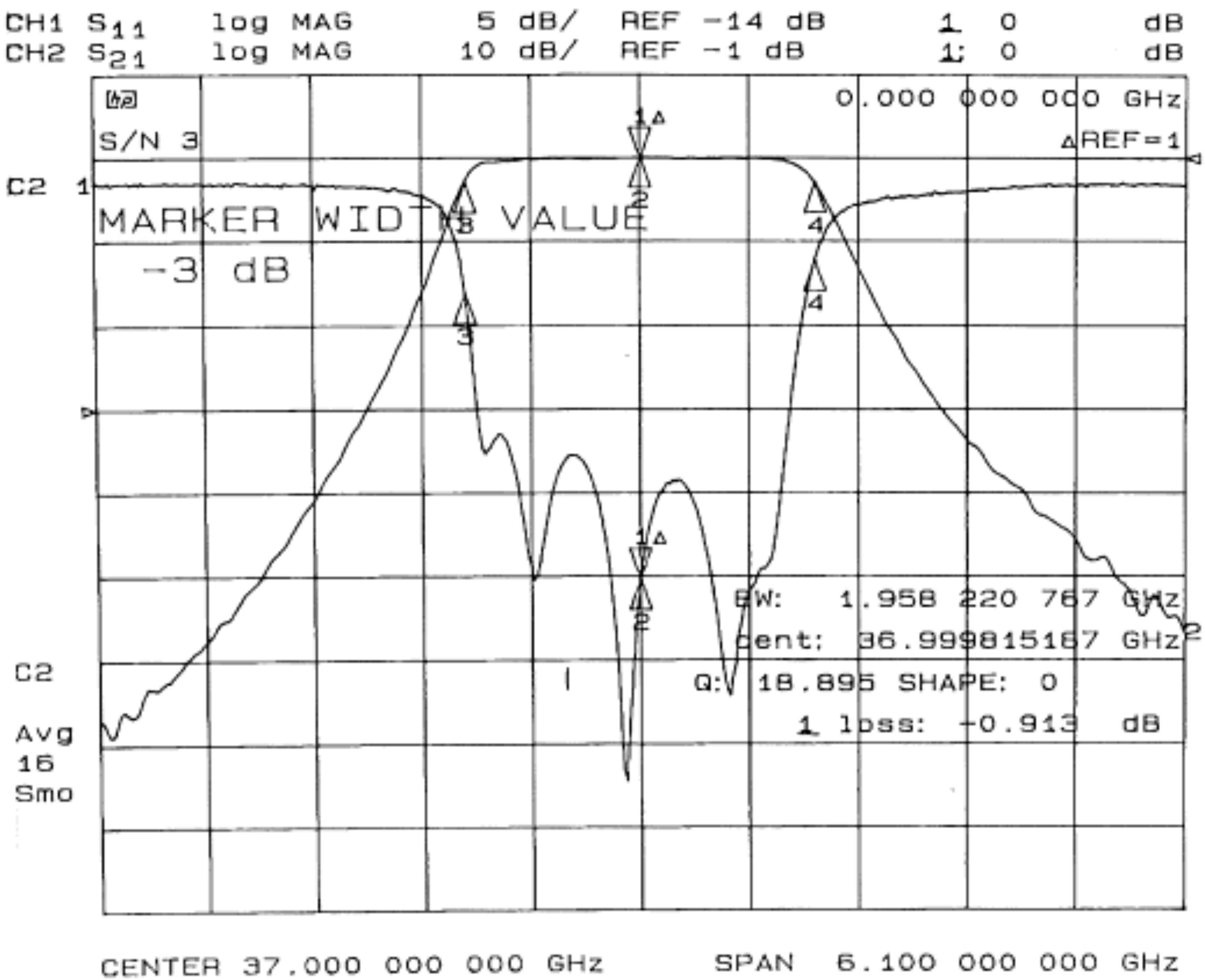
LNA Measured Performance

	Gain (S_{21})	Reverse Isolation (S_{12})	In. VSWR (S_{11})	Out VSWR (S_{22})	1dB Compression	Noise Figure (@ 40˚C)
37 GHz						
Requirement	25dB Min	$<S_{21}$	-6dB	-9.5dB	0dBm Min	2.8dB Max
Device 1	27dB	-55dB	-12dB	-13dB	8.7dBm	2.5dB
Device 2	28dB	-55dB	-9dB	-10dB	9.1dBm	2.75dB
10.7GHz						
Requirement	25dB Min	$<S_{21}$	-13dB	-13dB	0dBm Min	0.95dB Max
Device 1	33dB	-60dB	-21dB	-15dB	10.5dBm	0.89dB
Device 2	33dB	-60dB	-14dB	-19dB	11dBm	0.95dB

10.7 GHz Band Pass Filter Response



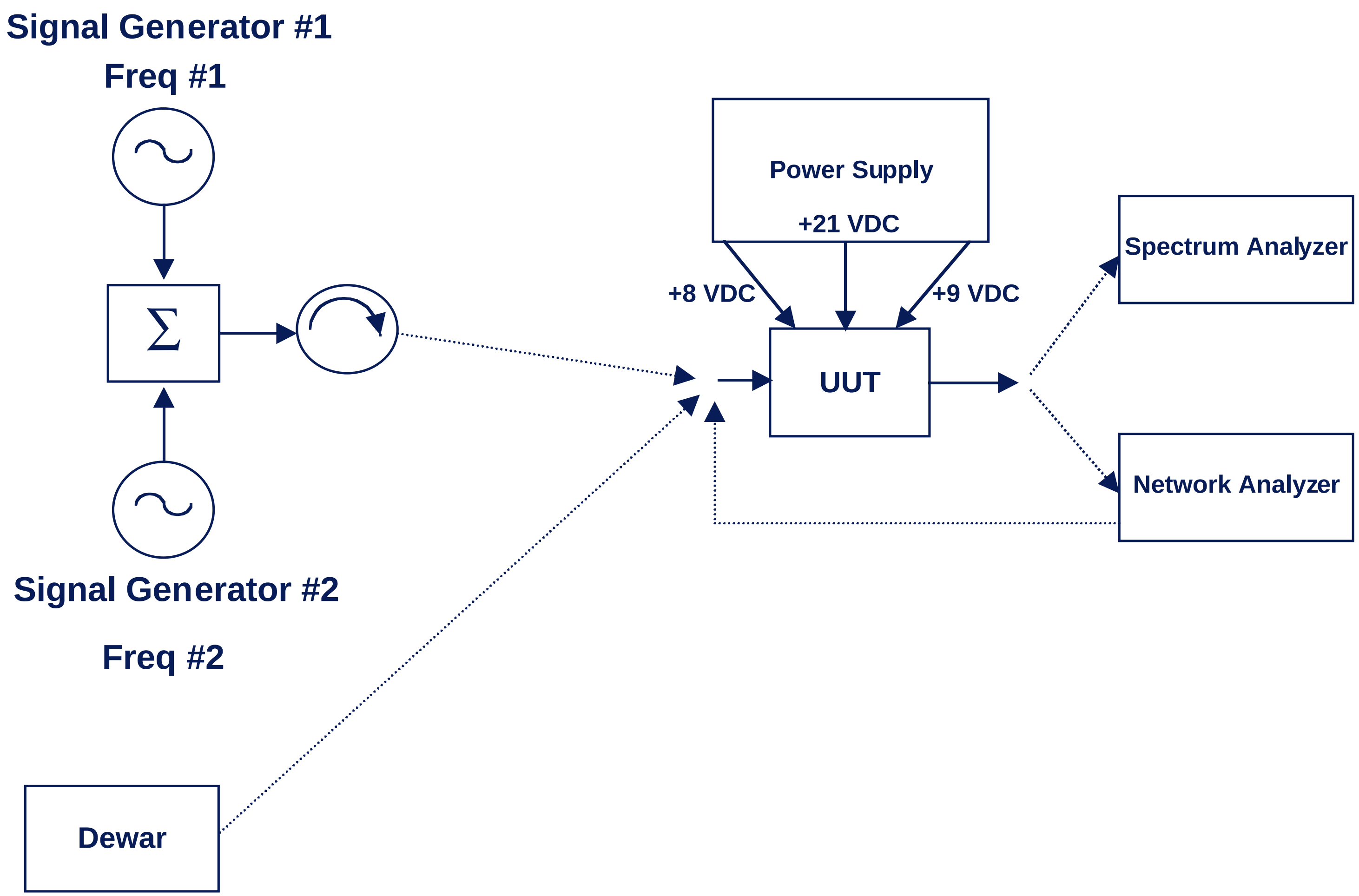
37 GHz Bandpass Filter Response



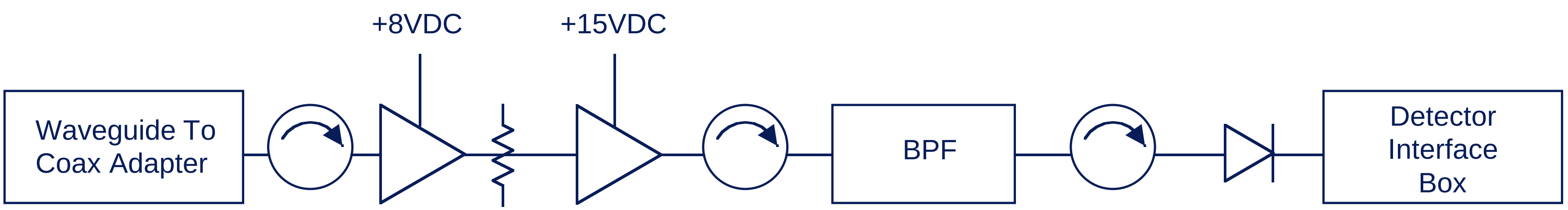
Receiver Channel Characterization

- 2 Channels @ 37 GHz, 2 Channels @ 10.7 GHz
- Measure Input Port VSWR And Noise Figure
- Frequency Response Testing
  - Center Frequency And Noise Equivalent Bandwidth
  - Input Power Level Testing
    - IP3
    - No-Damage Input Level
    - Receiver Gain
    - RF Amplitude Response

Receiver Channel Characterization Test Setup



RF Channel Characterization Breadboard Test Set-up



a) 2 DC Power Supplies

b) HP8566B Spectrum Analyzer

c) Two HP83650B Signal Generators

d) Power Combiner For 2-Tone Testing

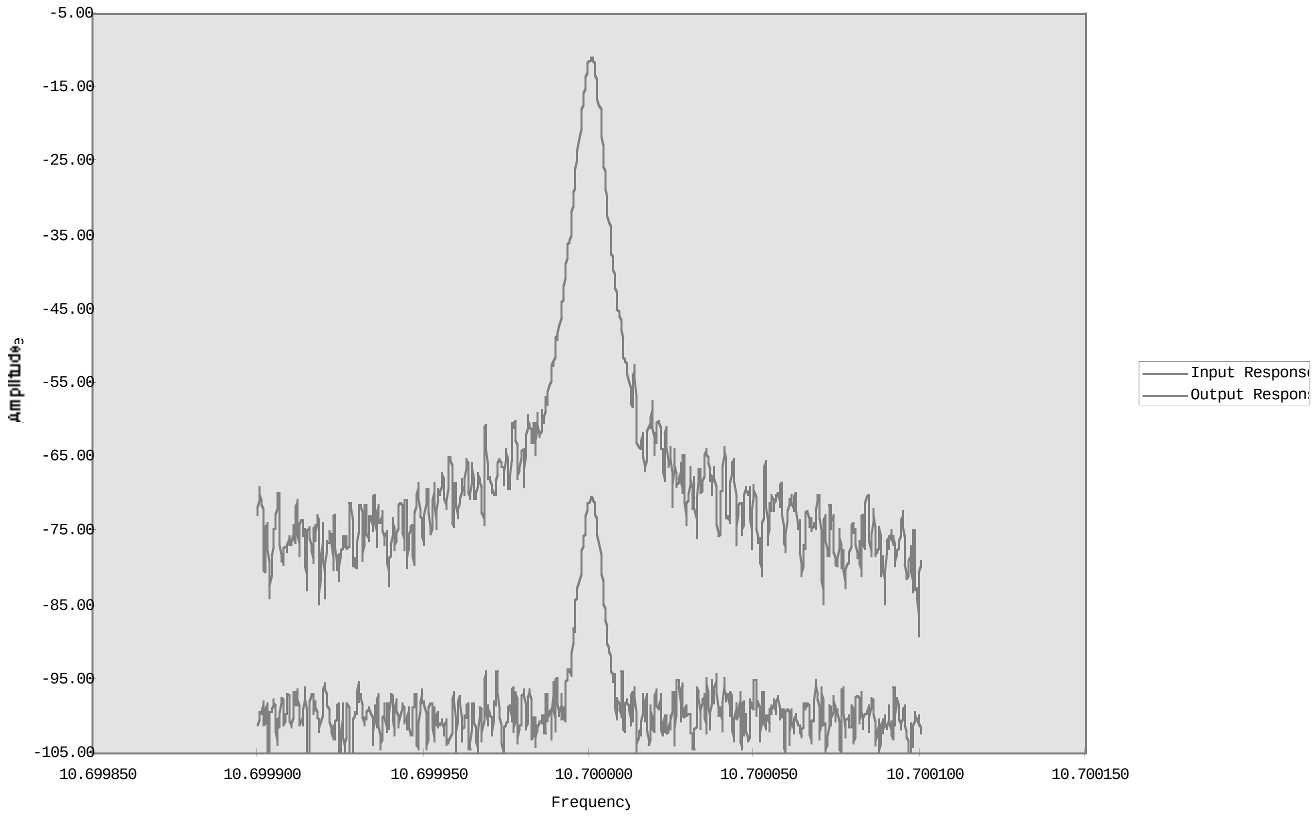
e) Detector Interface Box

RF Channel Characterization Breadboard Test Results, 10.7 GHz

Tests

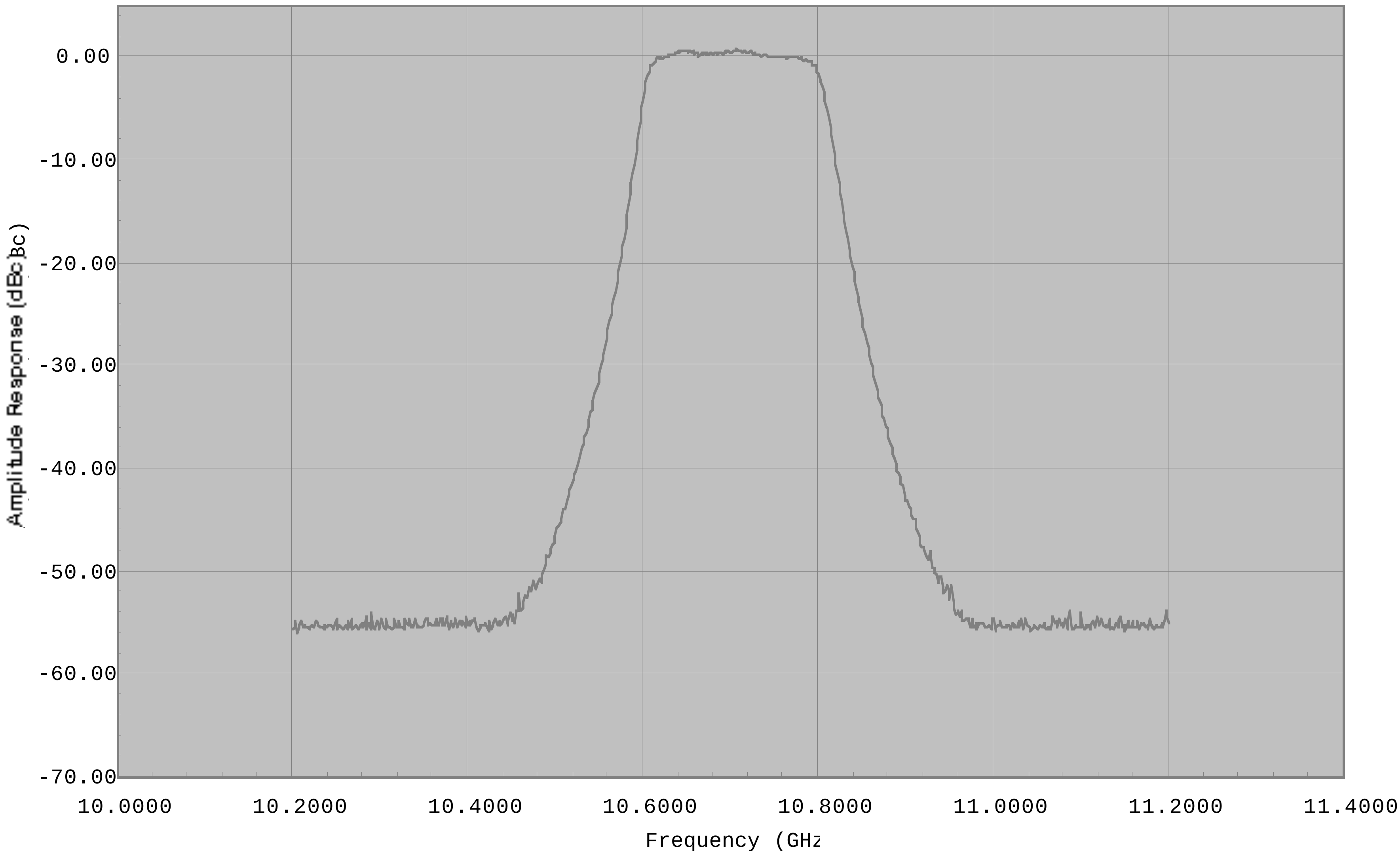
Characteristics	Requirement	Measurement
Gain	60.6 dB Min.	63 dB
Bandwidth	200 MHz	200 MHz
Linearity (RF, Detector)	< -60dB Harmonic Ratio	-64dB
Noise Figure	1.14 dB	.72 dB Without Input Isolator. Measured At Room Temperature
Input Gain Compression	60 dB	60 dB

10.7 GHz Breadboard
Center Frequency Gain

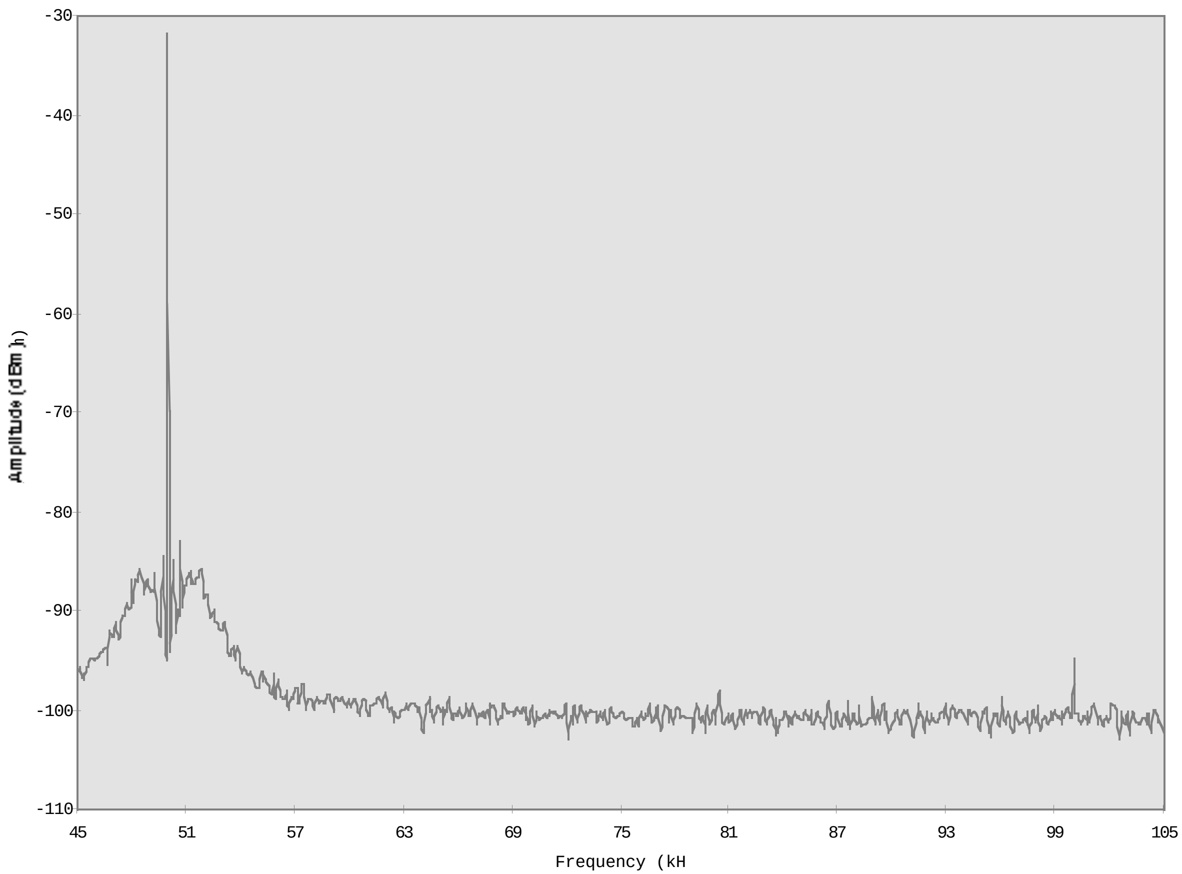


- **Gain Of 63 dB Measured At Room Temperature**
- **Meets Requirement Of 60.6 dB**

10.7 GHz Breadboard Amplitude Response



10.7 GHz Breadboard Post Detection Harmonic Distortion

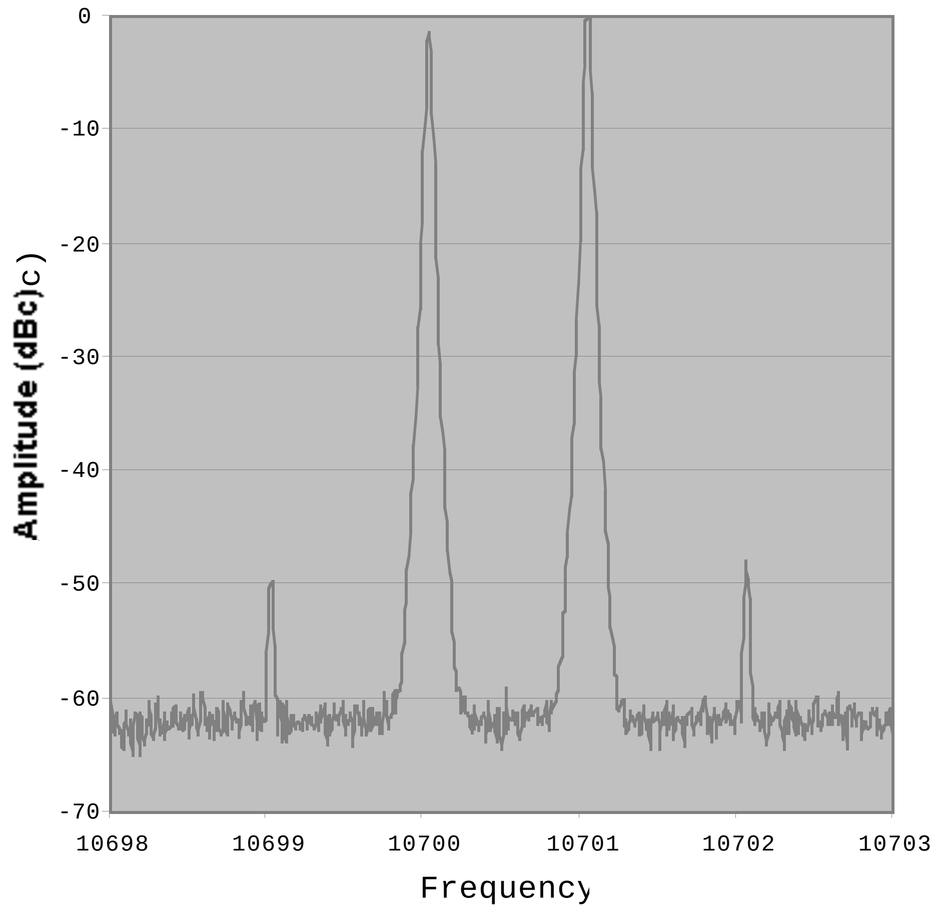


- Two Input Tones Separated Offset By 50 kHz Applied To LNA Input
- Measured -64 dB Harmonic Ratio Against A Spec Of -60 dB

10.7 GHz Breadboard IP3 Measurement Results

- **Power In Fundamental Output Tones Is -2.5 dBm**
- **Distortion Products At -47.8 dBc**
  - **Output $IP_3 = -2.5 + \left(\frac{47.8}{2}\right) = 21.4$ dBm**
- **With 63 dB Of Gain**
  - **Input $IP_3 = +21.4 - 63 = -41.6$ dBm**
- **Hot Calibration Equivalent Input Power Is -89 dBm**
- **Operational 3rd Order IMD Level Of**

  $2 \times (-89 + 41.6) = -94.8$ dBm



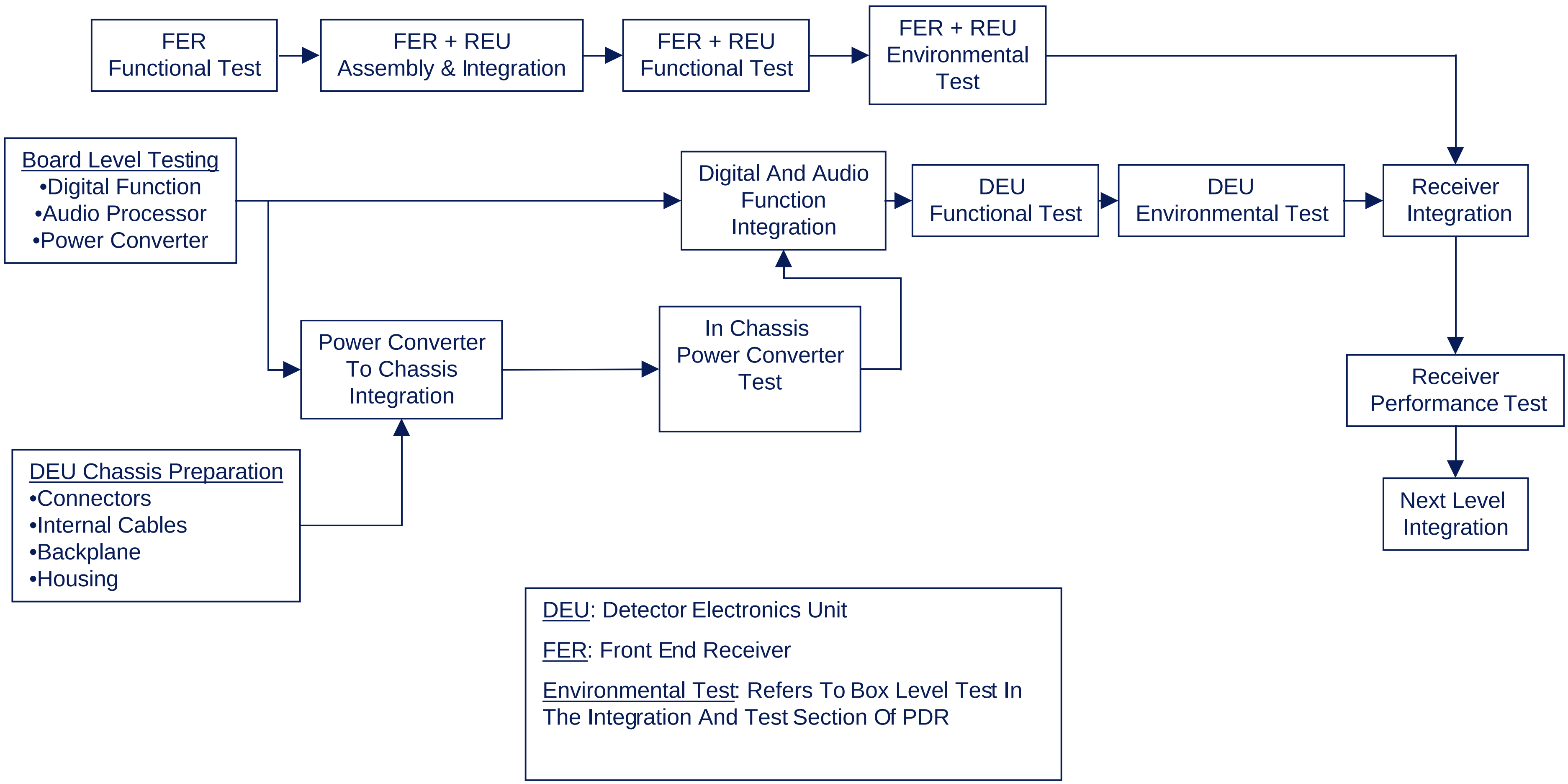
Receiver Front End Testing

- **Test Units: 1 Dual Channel Receiver At 10.7GHz And**
  1 Dual Channel Receiver At 37.0GHz
- **Test #1**
  - **Fix Input Noise Temp Using Dewar. Record Variations In Data Stream To Verify ΔT vs. Quiescent Input. Monitor Both RMS And Drift Responses**
- **Test #2**
  - **Thermal Cycle Receiver And Look For Performance Variations**
- **Test #3**
  - **Place RF Termination In Thermal Chamber And Measure Receiver Response For Various Noise Temperatures**

Audio Processor Characterization

- **DC Offset Level**
- **Audio To Digital Amplitude Response**
- **Differential Performance**
- **Temperature Testing**

Receiver Integration Flow

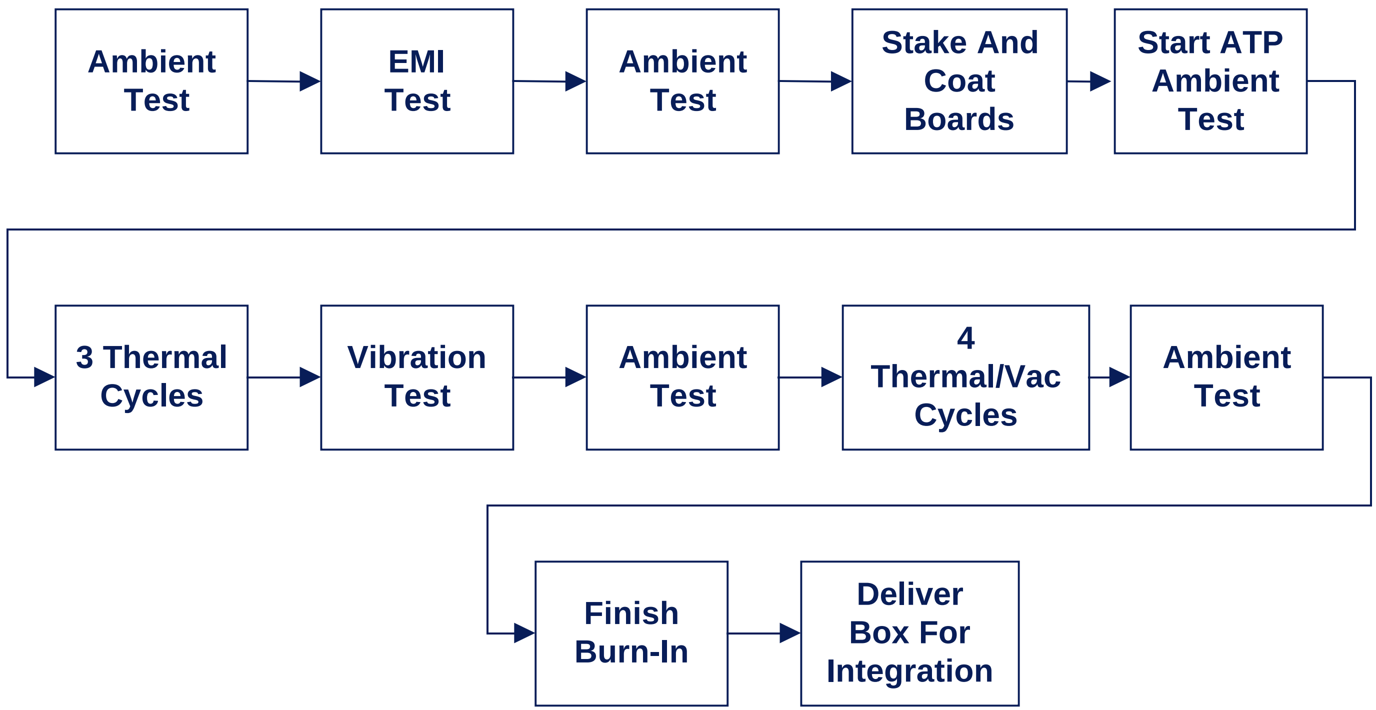


Receiver Test Plan Overview

- **Performance Testing**
  - **Test Receivers In A Condition That Closely Resembles The System Environment**

- **Environmental Stress Screening**
  - **Disclose Workmanship Defects**
  - **Assure Unit Reliability**

Electronics Box Level Test Flow



Total Of 200 Hours Burn-In

- 1st And Last Cycle Are 0 to 40° C
- Mid Cycles Are -20 To 60°C
- 2 Hour Dwells

Receiver AGE Requirements

- **This Test Equipment Will Be Required For Both WindSat Development And (Along With The EBB) To Support Flight Operations**

Test Equipment	Vendor
Miscellaneous Waveguide to Coax Transitions (37, 23.8), Waveguide, Adaptors, Coax Cables, Power Dividers	Misc
Network Analyzer, HP 8510C	Hewlett Packard
Verification Kit, Q1144A	Hewlett Packard
W/G Calibration Kit, Q1145A	Hewlett Packard
Spectrum Analyzer, HP 8566B	Hewlett Packard
Mixer, HP 1974Q	Hewlett Packard
Amplifier, HP 11957A	Hewlett Packard
Mixer, HP 11970K	Hewlett Packard
Logic Analyzer, HP 16500	Hewlett Packard
Oscilloscope, HP 54616C	Hewlett Packard
Precision Voltmeter, HP 3458A	Hewlett Packard
Frequency Synthesizer, HP 83650B	Hewlett Packard
Power Meter, HP 438A	Hewlett Packard
Bolometer, HP 8487D	Hewlett Packard
Racks, Cabling, etc.	Misc
Detector Interface Box	Custom Design
Delta T Test Set	Custom Design
Dewar 10.7 GHz And 37 GHz	NRL

Receiver On-Orbit Operations

- **Purpose:**
  - **Assess Receiver Health**
  - **Determine Need For Gain/Offset Adjustment**
  - **Detect Anomalous Operation**

- **Engineering Data:**
  - **Temperature and Voltage Monitors**
  - **Hot and Cold Calibration Events**

- **Process:**
  - **Perform Time Series Analysis On Engineering Data To Detect Short Term Effects**
  - **Perform Trend Analysis To Determine Degradation**
  - **Archive Engineering Data And Analysis Results**